The Properties of Special Concrete Using Washed Bottom Ash (WBA) as Partial Sand Replacement

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ABSTRACT

This paper presents the use of Washed Bottom Ash (WBA) as fine aggregate in special concrete. The WBA is a waste material that is taken from electric power plant and the source material is called as bottom ash. To substitute the amount of carbon usage in concrete the bottom ash was utilized and fully submerged in water for 3 days to produce as WBA with low carbon composition. The aim of the study is to investigate the feasibility and potential use of washed bottom ash in concreting and concrete applications. The results of the physical and chemical properties of WBA were discussed. Different concrete mixes with constant water to cement ratio of 0.55 were prepared with WBA in different proportions as well as one control mixed proportion. The mechanical properties of special concrete with 30% WBA replacement by weight of natural sand is found to be an optimum usage in concrete in order to get a favourable strength and good strength development pattern over the increment ages.

Keywords: *Bottom ash, Washed Bottom Ash, Properties, Special Concrete, Sand Replacement.*

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1.0 INTRODUCTION

Bottom ash (BA) from Electric power plant is estimated to increase in the develop country such as China, Malaysia and other countries where landfill for damped is limited. In the peninsula Malaysia, there are 4 famous electric power plants that use a coal (coal-fired) as a power material for generates electricity. There are at Perak, Johor, Selangor and Negeri Sembilan. The private sector is building a 2,100 MW capacity coal-fired power plant in Johor and another private sector group is building another 1,700mw capacity plant in Negeri Sembilan. TNB's electric power plant in Perak by using coal to the burning began operations in September 2002 with a capacity of 2100 MW (3 X 700 MW). This coal was taken directly from Sarawak. TNB also import high quality coal from Indonesia, Australia, the United States, Canada and also China. TNB will use 1.5 million tons of coal each year. To control fly ash and dust hovering in the atmosphere, recipients electrostatics was built and used for trapping 99% of ash and dust. While another waste material that disposed and after process of electicity is namely as coal bottom ash. This coal bottom ash is physically coarse, porous, glassy, granular, greyish and incombustible materials that are collected from the bottom of furnaces that burn coal. The type of bottom ash produced depends on the type of furnace and also the sources of coal. From the burning process of coal, 80% of product will become fly ash and remain 20% of product is bottom ash.

Bottom ash is collected at the bottom of the combustion chamber in a water-filled hopper, is removed by means of high-pressure water jets and conveyed by sluiceways to a decanting basin for dewatering followed by stockpiling and possibly crushing (Steam, 1978). Figure 1 show the typical steam generating system that illustrated the bottom ash dispose at the bottom furnace and fly ash is dispose to atmosphere by very tall chimney. The specific gravity (SG) of bottom ash is around 2 – 3 and shows the higher carbon content that ensuing in lower specific gravity. Table 1 presents the physical properties of bottom ash.

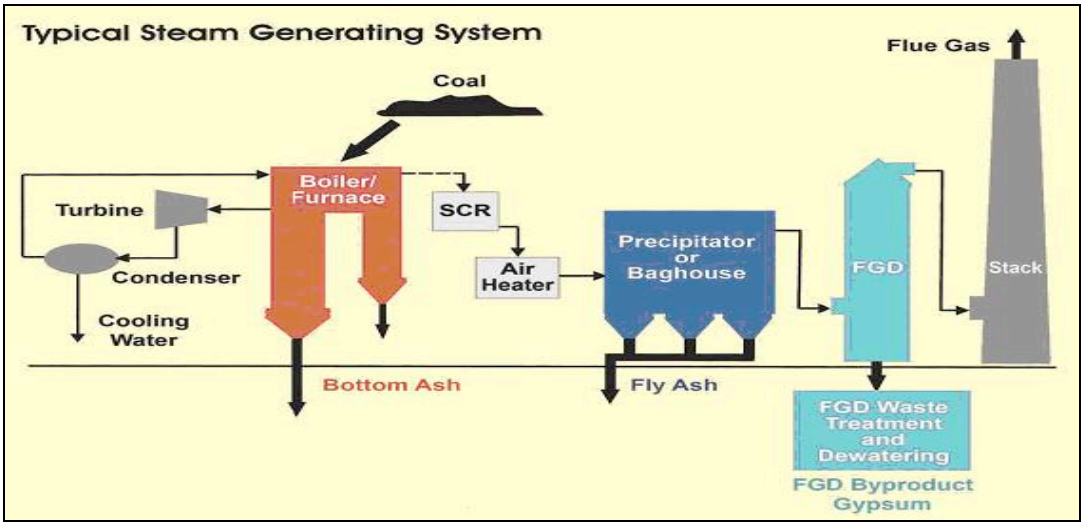

Figure 1: The production of coal combustion by-products in steam generating system. (NETL, 2006).

According to 2006 statistics, 45% bottom ash is used in transportation applications such as Asphalt Concrete Aggregate, road base material, Embankment or Backfill Material and structural fill (American Coal Ash Association (ACAA, 2006). Hjelmar et al (2006) said that bottom ash or municipal solid waste incinerator (MSWI) bottom ash in

Denmark is utilisation for back-filling (landfill) and as sub-based in road construction purposes. Besides that, bottom ash is also used as fine aggregate in producing lightweight concrete masonry and as cement replacement in structural and masonry purpose (Saikia et al, 2008), (Berg, 1998), (Jaturapitakkul and Cheerarot, 2003). Many investigation found that the bottom ash has some cementaneous properties in which may increasing the strength and long-term than concrete with natural sand. Siddique (2003) carried out strength properties test and indicate significant improvement in the strength of concrete by the addition of class F fly ash as partial replacement and can be effectively used in structural concrete. The physical properties of fine aggregate that carried out as shown in Table 2. Figure 2 illustrates the common applications of coal bottom ash. The strength and drying shrinkage of concretes with furnace bottom ash (FBA) as sand replacement at 0%, 30%, 50%,70% and 100% by mass, were studied at fixed water–cement ratios (W/C) and fixed slump ranges. (Bai et al, 2005). The results showed that, at fixed water–cement ratios, the compressive strength and the drying shrinkage decreased with the increase of the FBA sand content.

Table 1: The typical physical properties of bottom ash (Majizadeh et al., 1979)

Property	Bottom Ash
Specific Gravity	2.1 -2.7
Dry Unit Weight	7.07 - 15.72 kN/m^3 (45 - 100 lb/ft^3)
Plasticity	None
Absorption	0.8 - 2.0%

Table 2: Physical properties of aggregates (Siddique, 2003)

Property	Fine aggregate	Coarse aggregate
Specific gravity (SG)	2.63	2.61
Fineness modulus	2.25	6.61
SSD absorption (%)	0.86	1.12
Void (%)	36.2	39.6
Unit weight (kg/m3)	1690	1615

Besides that, many researchers have explored for utilizing bottom ash in special concrete application such as roller compacted concrete and self-compacting concrete. Ghafoori et al. (1997) carried out investigations on a series of laboratory-made roller compacted concretes (RCC) containing high-calcium dry bottom ash as a fine aggregate. Ratchayut Kasemchaisiri et al. (2008) presented the test results of mechanical properties of self-compacting concrete (SCC) incorporating bottom ash as partial sand replacement of 10%, 20% and 30% by weight. 10% replacement by weight of total fine aggregate showed a better durability, chloride penetration, carbonation depth and drying shrinkage compare to control SCC mix. The study for investigated the pozzolonic reactions and engineering properties of municipal solid waste incinerator (MSWI) bottom ash in slag blended cements (SBC) with various replacement ratios (Lin and Lin, 2006). The artificial light-weight aggregate made of a coal ash and a shale fine powder and it can be confirmed that it was a high-performance aggregate which maintained lightness, high strength, high water retentivity and harder composition (Hiroshi et al., 2008). This study explores the possibility and prospect of fully replacing of fine aggregate with washed bottom ash as a way of incorporating significant amount of washed bottom ash. Next, this paper also reports on the properties of special concrete with bottom ash as substitute for natural sand.

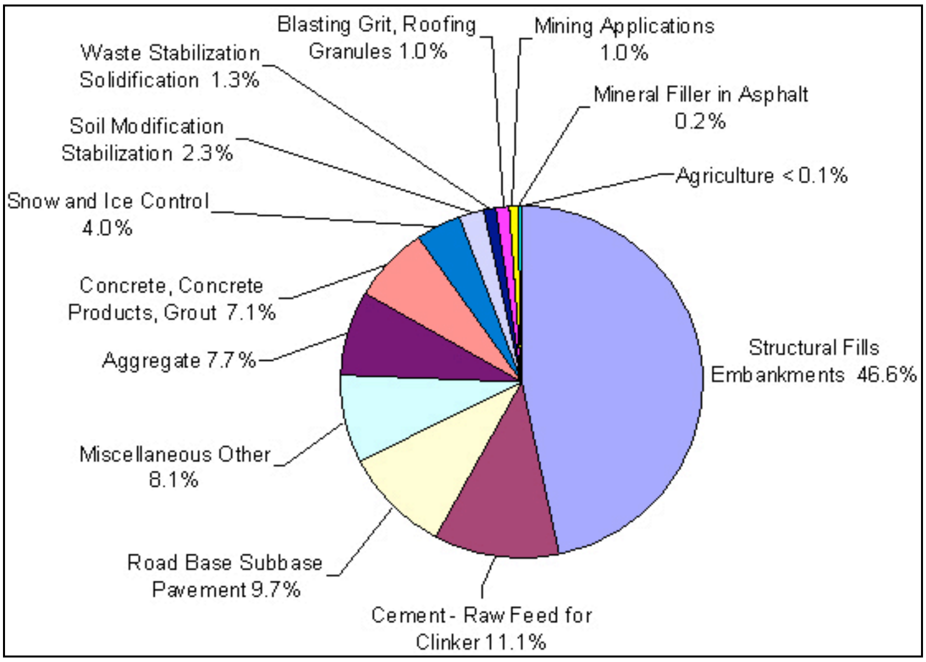

Figure 2: Bottom ash applications as a percentage of totals reused. (ACAA, 2006)

2.0 MATERIAL AND EXPERIMENTAL WORK

BA used was collected from the ash pond of TNB Electric power plant (Coal Power Station) in Perak. This bottom ash is of Q – DEJ + 10% Lati Coal type. Q – DEJ and Lati are noted as the origin of the coal located in Indonesia. Ash content in Q – DEJ and Lati was 10 – 13 % and 4% respectively. The Q – DEJ contain high fly ash and bottom ash while Lati contain low fly ash and high bottom ash. This BA has 9.76 pH concentrations. The discharging method of bottom ash was by circulating water and it is free from salt and chloride.

The BA used is first submerged in free water for 3 days to prevent carbon usage in concrete; hence the BA is called washed bottom ash (WBA). The WBA is then dried at normal temperature for 24 hours after which the sieve analysis is then carried out to get the particle size distribution accordance to BS 812-103.1: 1985. The WBA was also applied as partially sand replacement by weight in concrete mix to produce cube concrete for crushing test accordance to BS 1881: Part 116: 1983 . The WBA was substitute into concrete with its natural water to cement content of 0.55. The Portland cement used was a single source of Ordinary Portland cement (OPC). The fine aggregate was natural river sand complying with Zone 2 of BS 882: 1992. Concreting activity also utilized a 20 mm coarse aggregate of granite origin and clean tap water free from material deleterious to concrete and it complied to BS 3148: 1980.

3.0 PHYSICAL AND CHEMICAL PROPERTIES OF WASHED BOTTOM ASH

3.1 Sieve Analysis

Aggregate grading is very important in relation to the plastic properties and might effects the properties in harden state. Physical properties analysis conducted for WBA sample were sieve analysis and fineness modulus. WBA used to replace the fine aggregate is passed through 5 mm sieve. Sieve analyses of the natural sand and bottom ash sample were carried out as per British Standard (BS 410: 2000). The sample was initially sieved through 5mm in order to identify the fine particles in the bottom ash. The sieve grading is done by dry sieving using in-house method and the results are tabulated in Table 2. The results showed that 13.78% of the sample considered being of size greater than 2 mm which in fact could be considered as size between 5 mm to 2 mm. While the fines particle size of smaller than 36 µm is only 0.92%. Based on the sample tested, it was found that, the largest portion of washed bottom ash where 28.36 % of total sample is size of 150µm and classified as fine aggregates.

Table 3: Sieve analysis of washed bottom ash sand

BS sieve size	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative percentage passing (%)
>2 mm	0	0	100
2mm	13.78	13.78	86.22
1mm	16.57	30.35	69.65
710µm	5.79	36.14	63.86
600µm	4.87	41.01	58.99
500µm	3.64	44.65	55.35
425µm	4.17	48.82	51.18
300µm	12.29	61.11	38.89
150µm	28.36	89.47	10.53
36µm	9.62	99.09	0.91
<36µm	0.92	100	0
Total	**100**	365.33	-

Table 4: Grading limit for Fine Aggregate (Derived from BS 882)

BS sieve size	Percentage by weight passing BS sieve (%)							
	Overall limit	Additional limits			Zone 1	Zone 2	Zone 3	Zone 4
		C	M	F				
10 mm	100	-	-	-	100	100	100	100
5 mm	89-100	-	-	-	90-100	90 – 100	90-100	95-100
2.36 mm	60-100	60-100	65-100	80-100	60-95	75-100	85-100	95-100
1.18 mm	30-100	30-90	45-100	70-100	30-70	55-90	75-100	90-100
600 µm	15-100	15-54	25-80	55-100	15-34	35-59	60-79	80-100
300 µm	5-70	5-40	5-48	5-70	5-20	8-30	12-40	15-50
150 µm	0	-	-	-	0-10	0-10	0-10	0-15

Aggregate grading zone 2 and 3 is often described as concreting sand which is derived from BS 882: 1992. Table 3 show the grading limit for fine aggregates for the overall limit, additional limits and grading zone 1 to zone 4. According to the sieve analysis the WBA sand is not fully compliance to any grading limit of the specified four grading zones.

Nevertheless the WBA samples complied with grading zone 2 and zone 3 of the fine aggregate as shown in Figure 3 and Figure 4. The WBA is not compliance only for size between 150 µm up to 710 µm for specified grading Zone 2, whereas the others seem to approach the upper bound limits of this grading Zone. Therefore, it clearly indicates that the WBA composed of the large amount of smaller particles. In contrast, the WBA sample did not comply for particles of specified grading Zone 3 for sieve size between 710 µm up to part of 2 mm size portions. However, the sample is almost compliance to this zone limit. The higher zone number indicates a finer material. Therefore, the WBA is considered as fine sand which is applicable in any concrete applications.

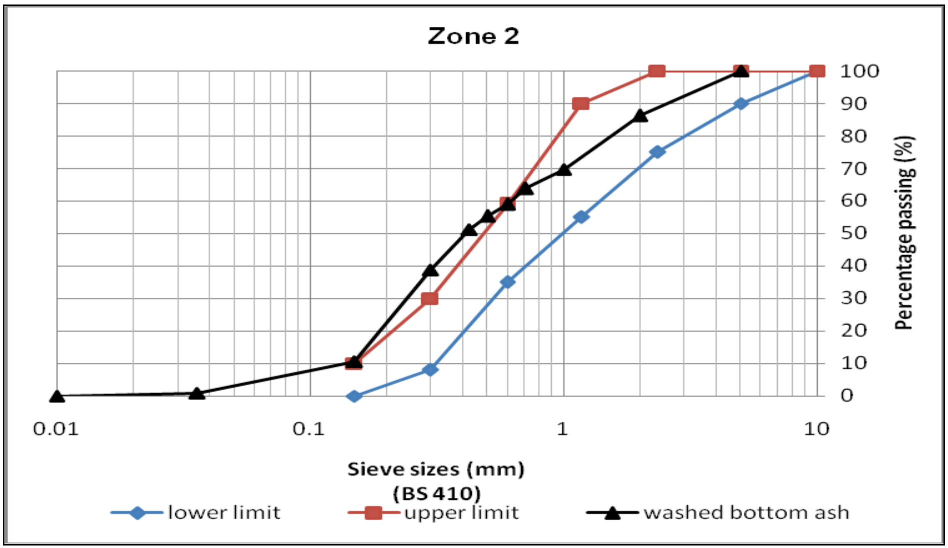

Figure 3: Grading curve of bottom ash for Zone 2

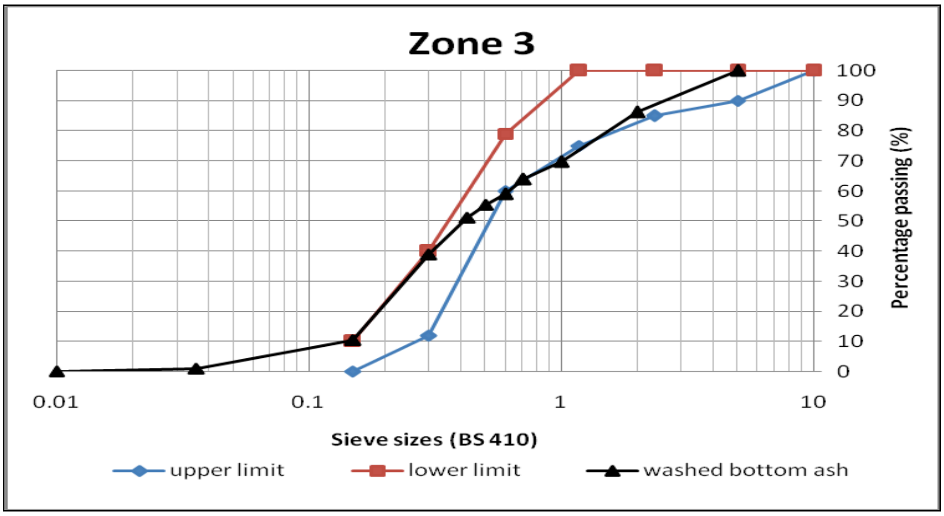

Figure 4: Grading curve of bottom ash for Zone 3

In Figure 5, the gradation curve of WBA sample clearly shows that the percentage passing are distributed in the middle range and fully complied with overall limits as given in BS 882 (1992). Therefore the WBA is suitable for general concrete applications. Considering the additional limits for grading sand, the WBA is also in compliance with the grading M and F except C as shown in Figure 6. The WBA is definitely not applicable for heavy duty concrete floor finishes as stated in BS 882 (1992). However, the process of limiting the size of bottom ash passing through 5 mm is more applicable to mortar rather that concreting sand.

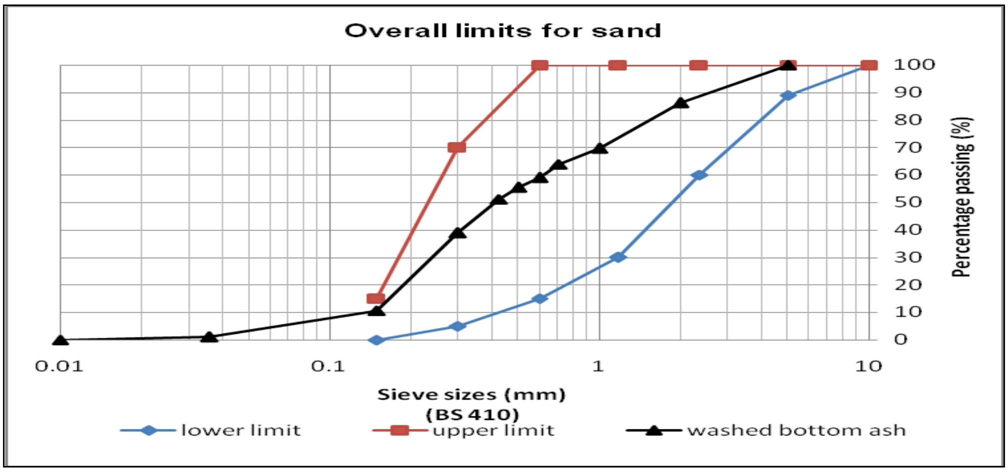

Figure 5: Grading curve of bottom ash for Overall zone

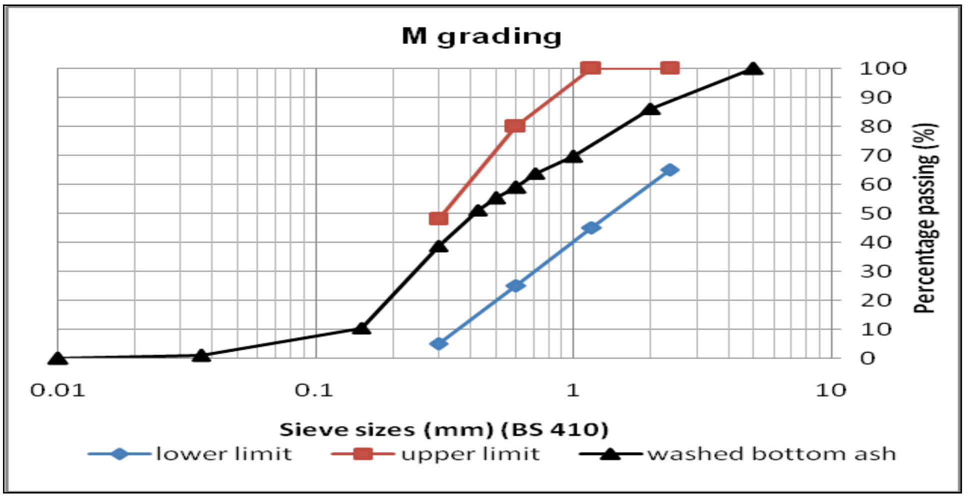

Figure 6(a): Grading curve of bottom ash for M grading.

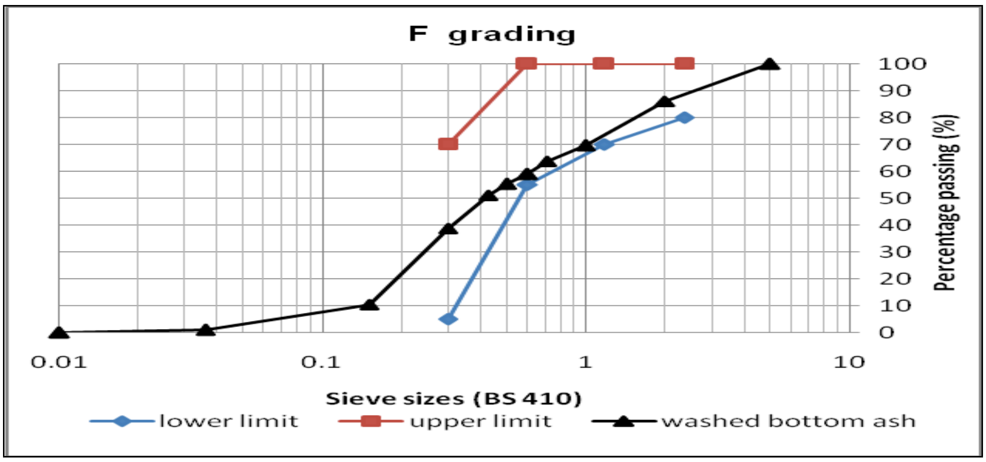

Figure 6(b): Grading curve of bottom ash for F grading.

The fineness modulus of bottom ash can is directly obtained from the results of WBA sieve analysis tabulated in Table 3. The fineness modulus is the summation of the cumulative percentage retained on the sieve standard series of 150, 300 and 600 µm, 1.18, 2.36, 5.0 mm up to the larger sieve size used. The calculated fineness modulus of bottom ash is 3.65 which is more than 3.5 and is considered to be very coarse. For categorization given in BS 822:1992 based on percentage passing the 600µm sieve between 55% to 100% would defined it as fine sand. While WBA has percentage passing 600µm of 58.99%. Therefore, the WBA is considered as fine sand (Alexander & Mindess, 2005).

3.2 Chemical Properties

Chemical composition of the WBA was determined by using XRF method on 600g samples and the results are tabulated in Table 5. In general the WBA is composed of 54.8% and 28.5% silica and alumina respectively. The lost of ignition is 2.46. Unlike natural sand, the chemical properties of WBA are almost same as Ordinary Portland Cement (OPC) hence it can partly function as cement in concrete matrix.

Table 5: Chemical properties of washed bottom ash and OPC

Chemical composition	Bottom ash Weight percent (%)	Cement (OPC)* Weight percent (%)
Silica, SiO_2	54.8	20.6
Alumina, Al_2O_3	28.5	5.7
Iron Oxide, Fe_2O_3	8.49	2.9
Titania, TiO_2	2.71	-
Magnesia, MgO	0.35	1.8
Calcium Oxide, CaO	4.2	63.6
Na_2O	0.08	0.12
K_2O	0.45	0.75
P_2O_5	0.28	-
SO_3	-	3.2
Cl	-	0.01
LOI at 1000°C	2.46	1.5

* (Bai, Ibrahim and Basheer, 2010)

4.0 MECHANICAL PROPERTIES OF WASHED BOTTOM ASH

4.1 Mixtures and Dosage

Five types of concrete were produced with the substitution of bottom ash by weight into natural sand in a various percentage of 10%, 20%, 30%, 40% and 50% and noted as M10, M20, M30, M40, and M50 respectively. Control mix concrete using 100% natural sand was produced for comparing its relative strength. Material for control mix as follows:

Free water = 210 kg/m^3
Cement = 403.85 kg/m^3
Sand = 686.34 kg/m^3
Gravel = 1119.81 kg/m^3

The compositions of concrete and WBA content as sand replacement are tabulated in Table 6.

Table 6: Mix detail of bottom ash concrete

Concrete	Cement (kg)	Natural sand (kg)	Washed Bottom Ash (kg)	Gravel (kg)	Water (kg)
Control mix	28.62	48.64	0	79.37	14.88
M10	28.62	43.78	4.86	79.37	14.88
M20	28.62	38.91	9.73	79.37	14.88
M30	28.62	34.04	14.60	79.37	14.88
M40	28.62	29.18	19.46	79.37	14.88
M50	28.62	24.32	24.32	79.37	14.88

4.2 Sample Preparation and Testing

The study of WBA as sand replacement involves mechanical properties analysis i.e. compressive strength evaluation. The compressive strengths were obtained for all concrete at 3, 7, 28, and 60 days of curing with three samples per age of testing to obtain the average value. Standard cube specimen sizes of 150 mm x 150 mm x 150 mm were used in confirmative with BS 1881-108:1983. The sample were exposed to constant temperature (24 ± 2 ºC) and constant relative humidity (95 ± 5 ºC) environment inside curing tank until the tested ages. At 24 hours after the concrete casting, the moulds were removing and the samples were kept into the curing tank until tested day. The weights of samples were recorded to measure amount of water abortion by capillary and determining the mass difference during the time interval of 1 day to 28 days.

4.3 Compressive Strength of Concrete

The compressive strength of concrete mixes made with various percentage of WBA as sand replacement inclusive of control sample (fully natural sand) was determined at 3, 7, 28, and 60 days of curing. It can be seen that the compressive strength of concrete mixes of sand replacement is much lower than control sample at all tested day.

The summary test results for all concrete are provided in Table 6 and presented in Figure 7. Generally, all concrete with WBA replacement has increment in strength until long term duration i.e. at 60 days. At the early strength of concrete, the percentage increment of compressive strength is between 77% to 89% which is almost similar to the control sample as tabulated in Table 7. M10 results in decreasing in compressive strength at 7 day, however the strength is getting increase after 7 days. However, this strength devolvement is not practical in concrete application. The used of WBA has revealed lower strength concrete compared to control sample strength. The washing method of bottom ash would cause it to flow with water. The loss of ash composing if fine particles causing the bonding between the aggregate to get loose due to pores in the concrete matrix. Fly ash is pozzolanic material. Cementitious compound in fly ash may produce when siliceous material reacts with calcium hydroxide at the presence of water at ordinary temperature. (USEPA, 2010). However, when the bottom ash is washed this reaction is completed causing it to lose it cementitious properties. Besides that, molecule in water may change the chemical content by breakdown to new heavy metal composition in the washed bottom ash resulting in lowering compressive strength.

Table 7: Compressive strength of concrete with WBA

Curing	**3 Days**	**7 Days**	**28 Days**	**60 days**
MIX	**Average Compressive strength (N/mm^2)**			
0% (control mix)	28.07	34.21	39.52	43.52
M10	17.56	16.52	21.41	23.71
M20	19	20.03	23.78	23.92
M30	18.79	20.81	24.65	27.44
M40	15.83	17.87	19.99	23.44
M50	14.4	17.3	21.2	22.44

Table 8: Early strength of concrete increment.

Concrete mix	**Early compressive strength increment at 7 days (%)**
Control mix	86.56
M10	77.16
M20	84.23
M30	84.42
M40	89.39
M50	81.60

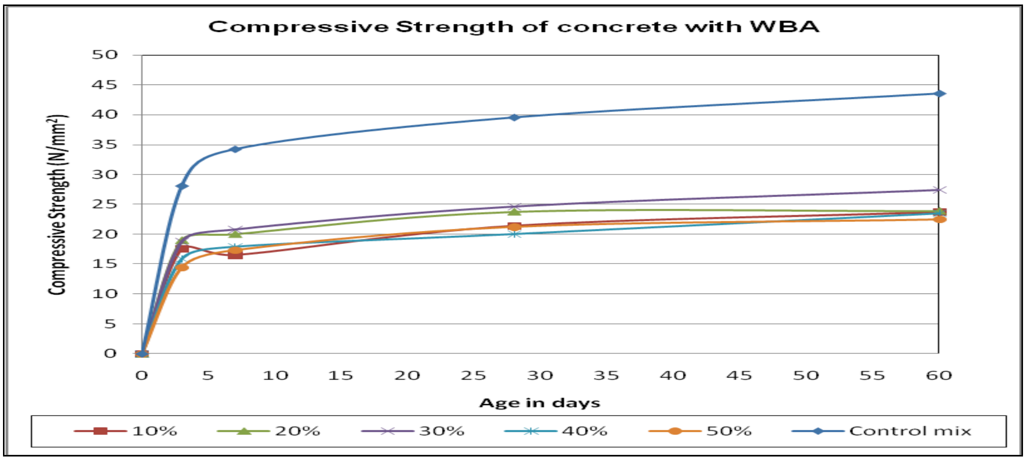

Figure 7: Behaviour of concrete strength with bottom ash

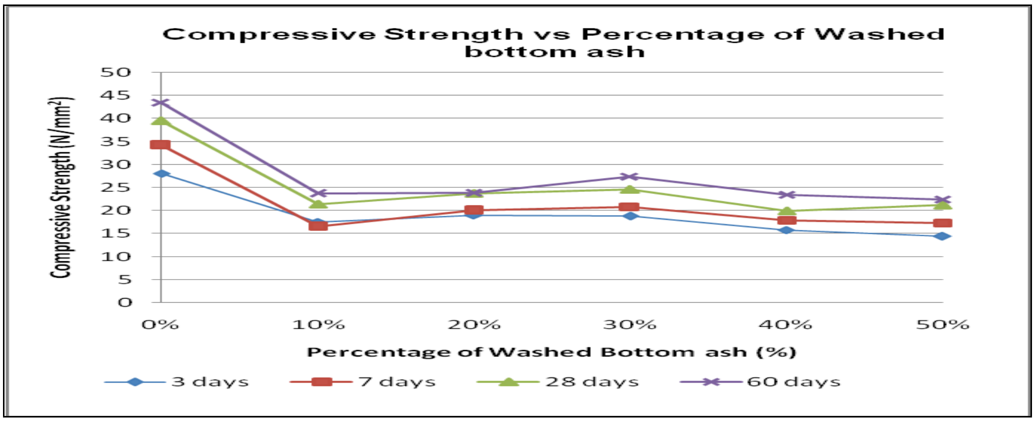

Figure 8: Effect of percentage replacement of Washed bottom ash in compressive strength.

Figure 8 illustrates the achievement of compressive strength of concrete at 3, 7, 28, and 60 days. It was found that the compressive strength at day 3 for M20 and M30 is the highest compared to other WBA concretes. Starting at 7 days, M30 recorded the highest strength until age 60 days of 27.44 N/mm^2. Therefore, it can be concluded that 30% of WBA as sand replacement in concrete is the optimum amount in order to get favourable strength, environment saving and a lowering cost.

5.0 CONCLUSION

The following conclusion may be drawn from this study:

1. Sieve analysis conducted on WBA from Electric Power Station, TNB Perak is more suitable used for mortar rather than concreting sand.

2. Bottom ash of 10% cement replacement by weight is not suitable for concrete because it has produce a lower strength concrete at the early ages which can results in ruptures during construction.

30% WBA replacement is found to be the optimum amount in order to get a favourable strength and good strength development pattern over the increment ages.

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