PROPERTIES OF CONCRETE USING TANJUNG BIN POWER PLANT COAL BOTTOM ASH AND FLY ASH

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ABSTRACT

Coal combustion by-products (CCPs) have been around since man understood that burning coal generates electricity, and its utilization in concrete production for nearly a century. The concept of sustainable development only reawaken our consciousness to the huge amount of CCPs around us and the need for proper reutilization than the current method of disposal which has severe consequences both to man and the environment. This paper presents the result of utilization of waste from thermal power plants to improve some engineering properties of concrete. Coal bottom ash (CBA) and fly ash were utilized in partial replacement for fine aggregates and cement respectively in the range of 0, 5, 10, 15 & 20% (equal percentages). The results of compressive strength at 7, 28, 56 & 90 days curing are presented because of the pozzolanic reaction; other properties investigated include physical properties, fresh concrete properties and density. The results showed that for a grade 35 concrete with a combination of CBA and fly ash can produce 28 day strength above 30 MPa.

Keywords: *Coal combustion by-products, coal bottom ash, fly ash*

1.0 INTRODUCTION

United Nation Sustainable Development report by [1] defined the concept of sustainable development as “the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs.” In engineering practice, sustainability does not stop at the development of new and environment friendly materials for construction purposes, but also the reutilization of materials that were erstwhile considered as waste by-products of industrial processes. According to [2], ‘During the last few decades, these “waste” materials have seen a transformation to the status of “by-products” and more recently “products” that are sought for construction and other applications.’

There have been some considerable developments on the research of coal bottom ash in concrete production by [3 – 6] from partial, near total and total replacements of fine aggregates in concrete with some encouraging results. The strength development of coal bottom ash concrete is relatively slow and usually starts beyond 28days [7]; a dramatic increase in performance is noticed beyond this period due to the delay in pozzolanic reaction. The compressive strength, flexural strength and density of bottom ash concrete decreased with an increase in the percentage of bottom ash replacement level [8].

In [9], “ when fly ash is used as an admixture in concrete, the early age compressive strength and long term corrosion resisting characteristics of concrete is improved.” A recent study by [10] on the development of brick using bottom ash and fly ash showed the 28 days strength of bricks ranged from 4.3-10.96MPa. They concluded that the bricks were comparable to that of normal clay bricks, because it satisfied the minimum strength for Class 1 bricks.

This investigation intends to utilize the special properties of fly ash to improve the properties of coal bottom ash concrete. This will fill in the knowledge gap where currently there is limited or no research done on the combination of the two materials in concrete in Malaysia. Moreover, it has been reported that the properties of CBA varies from one source (power plant) to the other. Partial replacement of CBA and fly ash was done in different percentages, with different mixes using fly ash as replacement for cement and coal bottom ash for fine aggregates. Fresh concrete properties, strength and density were investigated and the result discussed.

2.0 LITERATURE REVIEW

2.1 PHYSICAL PROPERTIES

According to the definition of ACI 116 (as cited in Karim et al., 2011 pp. 4138), fly ash is the finely divided residue resulting from the combustion of ground or powdered coal and which is transported from the firebox through the boiler by the flue gases, known in the UK as pulverized-fuel ash. Sizes may vary from less than 1µm to more than 80 µm and density of individual particles from less than 1Mg/m^3 hollow spheres to more than 3 Mg/m^3 (ACI Committee 232). Bottom ash on the other hand has angular particles with a very porous surface texture. It sizes ranges from gravel to fine sand with very low percentages of silt-clay sized particles; the ash is usually a well-graded material, although variation in particle size may be encountered.

The work of [11] showed that Tanjung Bin fly ash exhibit a well graded curve, ranging from fine silt to fine sand sizes, occurring within the range of 0.001mm and 0.6mm; the bottom ash gradation also exhibit a well graded size distribution ranging from fine gravel to fine sand sizes and the majority of the sizes occurred in the range of 0.075mm and 20mm. In [12], working on the same power plant showed that the grain size distribution of fly ash to be well graded from mostly silt to fine sand sizes. Majority of the sizes occurring between 0.001 and 0.06mm, they concluded that Tanjung bin fly ash had more silt particles while bottom ash sizes occurred in a range between 0.03 and 2.00mm.

The specific gravity of fly ash and bottom ash were found to be 2.3 and 1.99 respectively by [11] while [12] arrived at 2.19 and 2.39 respectively for fly ash and bottom ash. They attributed the wide range in specific gravity to two factors (1) Chemical composition with low Iron oxide content resulting in lower specific gravity and vice versa. (2) Presence of hollow fly ash particle or particles of bottom ash with porous or vesicular textures. Fly ash containing a large percentage of hollow particles would have a lower apparent specific gravity than one with mostly solid particles. The apparent specific gravity of bottom ash is also affected by the porosity of its particles. The bottom ash has a higher specific gravity than the fly ash indicating slightly higher Iron oxide content present in the chemical composition of the bottom ash. This can be attributed to the presence of highly porous-popcorn –like bottom ash particles.

2.2 CHEMICAL PROPERTIES

The work of [Muhardi et al., (2010); Fawzan (2010); and Naganathan et al., (2012)] as cited in [13], showed that the major components of the three thermal power plants bottom ash in Malaysia studied were Silica, Alumina & Iron oxide with percentage compositions of 9.78 - 49.4%, 20.75 - 23% & 17 - 37.1% respectively. And that bottom ash used by [Muhardi et al., and Fawzan] is a Class F because the sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ exceeds 70% and according to ASTM C618 this can be attributed to the use of Bituminous or Anthracite Coal which produce low calcium content. The bottom ash studied by [Naganathan et al.,] is a Class C because the sum is less than 70% but greater than 50%. Class C is generated from the combustion of Lignite or Sub-bituminous coal with a high calcium content. Smaller percentages of potassium, magnesium & sodium are also present in Malaysian power plant bottom ash with traces of barium, manganese

& zinc. BS 3892: Part 1: 1993 specified an SO_3 content of less than 2.5% and a maximum of 5.0% by ASTM C618 and Na_2O alkali of not more than 1.5%.

Table1: Chemical composition of OPC, Bottom ash, Fly ash & requirements.

	Naganathan et al., (2012)	Muhardi et al., (2010)		Awang et al., (2011)		ASTM C618 requirement on the use of fly ash.
Chemical contents	Ordinary Portland Cement	Coal bottom ash (%)	Fly ash (%)	Coal bottom ash (%)	Fly ash (%)	
SiO_2	21.54	42.7	51.80	46.60	47.10	SiO_2 + Al_2O_3 + Fe_2O_3 > 70 Class 'F'
Al_2O_3	5.32	23.0	26.50	26.10	30.00	
Fe_2O_3	3.60	17.0	8.50	12.40	7.34	
CaO	63.60	9.80	4.81	8.31	7.21	>10 Class 'C'
K_2O	-	0.96	3.27	1.34	1.62	-
TiO_2	-	1.64	1.38	1.84	1.83	-
MgO	1.00	1.54	1.10	1.26	1.52	Max 5.0
P_2O_5	-	1.04	0.90	0.62	1.37	-
Na_2O	-	0.29	0.67	0.62	0.72	Max 1.5
SO_3	2.10	1.22	0.60	0.30	0.32	Max 5.0
BaO	-	0.19	0.12	0.13	0.27	-
MnO	-	-	-	-	-	-
ZnO	-	-	-	-	-	-
SrO	-	-	-	0.19		-
CO_2	-	-	-	0.10	0.10	-
Gs	3.15	1.99	2.30	2.39	2.19	-

2.3 MECHANICAL PROPERTIES

Research on the use of coal bottom ash and fly ash in concrete has been carried by partially replacing fly ash with cement and grinding bottom ash particles to smaller sizes as a pozzolana; bottom ash as a partial or total replacement of fine aggregate and as coarse aggregate using large size particles. According to [14], large size (greater than 6mm) bottom ash can be used as coarse aggregate and small size can be used as fine aggregate.

Investigations by [5] showed that it is possible to manufacture lightweight concrete with SSD in the range of 1560 – 1960 kg/m^3 and a 28 day compressive strength in the range of 20 - 40 N/mm^2. The test which was conducted in two series showed that the first series, compressive strength decreased at all ages, but for the second series, the decrease was only observed at 3 day strength. However, there was an increase in strength at 7 & 28days when natural sand and coarse aggregates were replaced

The use of fly ash as an admixture (equal quantity of sand replacement) by [9] to evaluate the compressive strength development and corrosion-resisting characteristics of concrete mixes made with fly ash additions of 0, 20 & 30%, and water – cement ratios of 0.35, 0.40, 0.45 & 0.50 concluded that addition of fly ash as an admixture increases the early age compressive strength and long –term corrosion – resisting characteristics. The work of [15] reported that the strength differential between fly ash concrete specimens and plain concrete specimens became more distinct after 28 days: this is after he replaced fine aggregates with class F fly ash in the range of 0, 10, 20, 30, 40 and 50% at 7, 14, 28, 56, 91 & 365 days. He further stated that compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of fine aggregate (sand) replaced fly ash concrete continued to increase with age for all fly ash percentages.

From the work of [16] "there was a slight decrease in compressive strength with an increase in the bottom ash content" this observation was made when they use class C fly ash and class F bottom ash with the bottom ash as coarse aggregate and class F fly ash with class C." Bakoshi et al., (1998) as cited in Siddique (2003, pp. 540) used bottom ash in amounts of 10 – 40% as replacement for fine aggregate. Test indicate that the compressive strength and tensile strength of bottom ash concrete generally increases with the increase in replacement ratio of fine aggregate and curing age.

3.0 MATERIALS AND METHODS

3.1 MATERIALS

The cement used in this research is Lafarge Phoenix Brand, a brand of Portland Composite cement which satisfied the specification for ordinary Portland cement MS EN 197-1:2007[17]. It is an eco-friendly building material with a minimum of 20% recycled content in its chemical composition and concrete made from this cement releases low levels of hydration heat in the early stages of hydration process.

The CBA and fly ash was obtained from Tanjung Bin power plant in Pontian, Johor. The fly ash was obtained directly from the bottom of the electrostatic precipitator into a sack because of its powdery and dusty nature while the coal bottom ash is transported from the bottom of the boiler to the ash pond as liquid slurry in a 200-250mm diameter pipes. At the lab, it was sprayed in a mixing tray to remove the excess moisture, and then placed in an oven at 105° +/- 5°C. The CBA particles were sieved and the size passing 4.75mm BS Sieve was used in the research. Likewise graded river sand passing the same gradation size was used. Coarse aggregate from crushed stone with a maximum nominal aggregate size of 19mm was used, both the fine and coarse aggregate conform to BS 812: Part 103-1990[18]: Testing Aggregate specification.

3.2 MIX PROPORTION

A control mix containing OPC, natural sand and crushed rock aggregate was designed for a compressive strength of 35MPa at 28 days with a slump range of 25-75mm non-air entrained concrete using ACI Method of mix design. Natural sand was partially replaced with CBA in the range of 5, 10, 15 & 20%. Similar proportion was used for cement replaced with fly ash. The mix proportion is given in table 1 for 9No. 150mm^3 cubes moulds. The water to cementitious ratio (cement + fly ash) was kept constant at 0.48 with many trial mix conducted to ensure that the workability was in the range of the designed slump.

Table 2: Mix design for fly ash, CBA concrete

Quantities	Cement(kg)	Fly ash (kg)	Water (kg)	Fine Agg. (kg)	Bottom ash (kg)	Coarse Agg. (kg)
Per m^3	395.83	-	190.00	617.17	-	1088.00
Control	4.01	-	1.92	8.02	-	12.03
5%FA 5%CBA	3.81	0.20	1.92	7.62	0.40	12.03
10%FA 5%CBA	3.61	0.40	1.92	7.22	0.80	12.03
15%FA 5%CBA	3.41	0.60	1.92	6.81	1.20	12.03
20%FA 5%CBA	3.21	0.80	1.92	6.41	1.60	12.03

3.3 BATCHING AND MIXING

Batching was done by weight using the mix proportion presented in table1. The mixing process was done using mechanical tilting mixer and the procedure was the same as that of the normal weight concrete. Upon emptying the content of the mixer, slump test was conducted in accordance with BS 1881: Part 102: 1983[19] to measure the consistency.

3.4 CASTING AND CURING OF SPECIMEN

Sixty numbers of 150x150x150mm concrete cube samples were casted including the complete batch of 7day samples that were repeated. Each batch mix was made to produce nine cubes to be tested for compressive strength at 7, 28, 56 & 90 days. The curing duration was extended beyond 28 days to study the effect of pozzolanic reaction of CBA which usually manifest after 28days. Density was also determined at the above mentioned curing duration.

The fresh concrete was casted in steel mould in three layers and tampered with a tamping rod, the side of the mould rodded and then compacted on a vibrating table. While on the vibrating table, additional sample was added to fill in the gap created as a result of the vibration. The duration of the vibration usually lasted for 45seconds or when air bubbles appeared on the surface of the concrete, but it should be noted that total absence of entrapped air is not possible. The casted specimen was placed in the laboratory for 24 hrs at 27+/-1°C in accordance to MS 26: Part 1:2009[20] until testing day. Immediately after demoulding, the samples were weighted before immersion in a curing tank.

3.5 DETAILS OF TESTS

Grain size analysis conducted was in accordance to BS 1377-2: 1990[21], more so, an analysis of fine aggregate & bottom ash was conducted with respect to BS 410:2000[22]. Specific gravity was tested using the pycnometer procedure using ASTM D 854-00[23]. The determination of moisture condition of the CBA on oven – dried condition at the time of conducting the experiment was done in accordance to BS EN 1097-6: 2000[24] for a duration of 10, 20 & 30 minutes to ascertain the initial water absorption of the bottom ash. Fresh and hardened concrete properties were determined for the sample prepared; the slump and compacting factor tests were carried out in accordance with BS 1881: Part 102: 1983[19] and BS 1881: Part 103: 1983[25] respectively. The compressive strength test and the density test were carried out in accordance to BS 1881: Part 116: 1983[26] and BS 1881: Part 114: 1983[27] respectively.

4.0 RESULTS AND DISCUSSION

4.1 PHYSICAL PROPERTIES

The sieve analysis of CBA was conducted in accordance to BS 410:2000[22]. The result of the analysis showed that it is distributed from fine gravel to fine sand with a very large percentage of the sand from coarse to medium sand conforming to BS 882:1992[28] requirements.

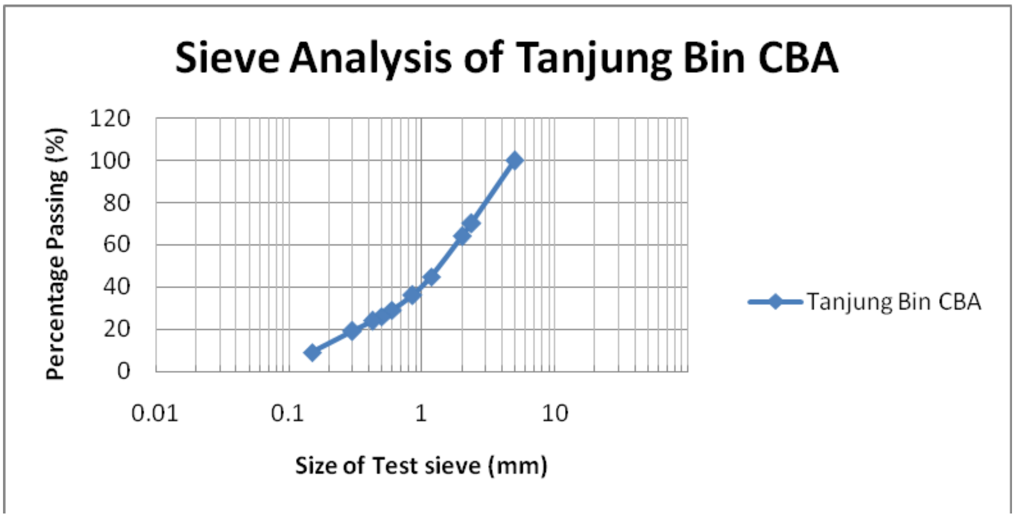

Figure 1: Graphical representation of grain size curve.

The grading analysis of CBA in accordance to BS 410:2000[22] is presented in table 3. The material passing 600µm and 300µm (No. 30 and 50 ASTM) sieve sizes were 29.6 and 18.8% respectively, showing that there were less material in that range, and about 45.2% passing 1.18mm (No. 16) meaning there were more materials larger than 150µm (No. 100) sieve. For the grading limits, Tanjung Bin coal bottom ash satisfies zone 1 and 2 for 600µm, zone 1, 2, 3 and 4 for 300µm (see appendix). The requirements for 1.18mm satisfy for zone 1. BS 882: 1973[29] is based on the percentage passing 600µm.

Table 3: Grain size analysis of CBA from Tanjung Bin

BS sieve size	Percentage retained (%)	Cumulative percentage retained (%)	Cumulative percentage passing (%)	BS 3797:1990		ASTM C 330-89 (%)
				Grade L1 (%)	Grade L2 (%)	
5.00mm	0.0	0	100	90-100	90-100	85-100
2.36mm	30.0	30.0	70.0	55-100	60-100	-
2.00mm	5.6	35.6	64.4			
1.18mm	19.2	54.8	45.2	35-90	40-80	40-80
850µm	8.8	63.6	36.4			
600µm	6.8	70.4	29.6	20-60	30-60	-
500µm	3.2	73.6	26.4			
425µm	2.0	75.6	24.4			
300µm	5.6	81.2	18.8	10-30	25-40	10-35
150µm	10.0	91.2	8.8	5-19	20-35	5-25
75µm	3.2	94.4	5.6			

Therefore additional limits requirements was satisfied for all the limits of coarse, medium and fines aggregates. Aggregate grading zone 2 and 3 is often described as concreting sand which is derived from BS 882: 1992[28].Tanjung Bin coal bottom ash satisfies the requirement of ACI 213 for fine lightweight aggregate because it has a 100% passing the No.4 sieve size. Grading requirement for lightweight fine aggregate given by BS 3797:1990[30] and ASTM C 330-89 [31] were met but it is always at the lower bound, which means that Tanjung Bin coal bottom ash has a higher percentage of coarse particles.

Figure 2(a) coarse bottom ash sample 5mm and above. **Figure 2(b)** fine bottom ash sample on fine sand passing 5mm sieve size.

The specific gravity of the fly ash and CBA were found to be 2.45 and 1.9 respectively comparatively lower than the specific gravity of cement 3.15 and natural sand 2.6. According to [11], the specific gravity of fly ash has more range with the variety values of and average lower than natural soils due to different chemical content and particle structure; compared to natural sand that is of the same composition. Also, a porous or hollow bottom ash may present a specific gravity as low as 1.6, the porous nature of the bottom ash results in excessive water intake. In [32], it was reported that original bottom ash has a specific gravity of 2.13; ground bottom ash 2.70 and Portland cement 3.14. They attributed the variation in specific gravity between original and ground bottom ash to lower porosity as a result of grinding the ground bottom ash. This result of Tanjung Bin coal ash indicates a low iron oxide and lime content which conforms to the result of [33]. Another factor that might be responsible for the lower specific gravity is the coarse texture of the sand, the result of the sieve analysis indicated that it has a high percentage of particles from 5mm to 1.18mm. The work of [35] showed that bottom ash with low Gs posses a porous and vesicular texture; also [36] reported that porous bottom ash may present low Gs, sometimes as low as 1.6. The state of the material at the time it was utilized also affect the specific gravity, the bottom ash was oven – dried at the time it was tested for specific gravity. Studies have shown that dry bottom ash has a lower specific gravity than saturated bottom ash

The result of the 24hr water absorption of CBA showed that the absorption was 19% which is in line with the specification of ACI 213R[37], that lightweight concrete aggregate generally absorb from 5-20% by weight of dry aggregate depending on the pore structure of the aggregate. This is in contrast to normal weight concrete aggregate which absorb less than 2% moisture.

The CBA aggregate during testing for water absorption rate, was utilized in oven – dried condition and soaked in distilled water for 10, 20 & 30 minutes. It was then surfaced dried before placed in an oven for the equal amount of time it spends in the water. Upon, removal from the oven, it was spread to cool to avoid taking reading with temperature difference. The percentage water absorption rate was 8, 16 & 17 for 10, 20 & 30 minutes respectively. It was observed that the absorption for 10 – 30 minutes was relatively high compared to that of 24 hours water absorption, this is due the fact that former were oven – dried for the equal amount of time they spend in water before it was tested while the latter was dried for 24 hours before it was tested. Some moisture might still be present in the CBA at the time of testing for the 10 – 30 minutes soaking, because the aim is to establish the rate of water absorption over a specified period of time. Another factor that might have warrant the high initial absorption has to do with the particle size of the CBA, the sieve analysis result indicated that it is distributed from fine gravel to fine sand with a large percentage of the sand in the coarse to medium sand gradation. Therefore, the tendency of the particles to have a large porous surface area is very high.

Generally, lightweight aggregates have a high initial absorption of moisture, then the process slow down at a later stage when the inner pores are saturated. According to [38], " for many purposes, the early absorption is the important one and this range from about 5 – 15% of the dry weight after 24 hrs, perhaps 3% to 12% after 30 minutes. The typical data normal aggregates are 0.5% to 2% for 24hrs absorption." Ultimately, the rate of absorption of lightweight aggregate depends on the aggregate type, particle size of the aggregate, the initial condition of the aggregate (whether oven-dried or pre-wetted intentionally or otherwise) as we have seen in the case of coal bottom ash.

4.2 MECHANICAL PROPERTIES

4.2.1 FRESH CONCRETE PROPERTIES

The result of the workability of the fresh concrete was correlated between slump and compacting factor. The results from table 3 indicate that 5% to 15% replacement of CBA/ fly ash exhibit workability within the desired range of 25-75mm slump except for the 20% replacement. BS 1881: Part 102[19] 1983 stipulates that the test method appropriate for medium workability is compacting factor and slump, even though slump is attacked as useless and poor indicator of concrete strength. Its main purpose is to determine variations in uniformity that might occur in a given mix.

Table 4: Workability of the fresh concrete

Sample	Slump measured (mm)	Compacting factor	Workability
Control	55	0.903	Medium
5%	25	0.952	High
10%	40	0.934	Medium
15%	45	0.930	Medium
20%	15	0.882	Low

The increase in the slump value that was observed from 25mm at 5% to between 40 – 45mm at 10 – 15% might be an indication that the water content might have increased, but in this situation, the water - cement ratio was constant at 0.48. According to [39], for a constant workability, the reduction in the water demand of concrete due to fly ash is usually between 5 and 15% by comparism with a Portland cement only mix having the same cementitious material content; the reduction is larger at higher water – cement ratios. Another reason responsible for the increased workability is the "ball-bearing effect" of the fly ash; this is as a result of the spherical shape of the fly ash, the finer particles becomes adsorbed on the surface of cement particles enough to cover the surface of the cement particles; the water demand for a given workability is thus reduced. The reduction in the water demand becomes larger with an increase in the fly ash content up to about 20%. The drop in workability (high – low) was noticed as a result of the percentage increase in bottom ash quantity in the mix. In conclusion, according to Helmuth (1987) [as cited in Neville, 95 pp. 654], 'the action of fly ash, like that of Superplasticizers, on water demand is through dispersion and adsorption of the fly ash particles of Portland cement.' And the lower specific gravity of fly ash compared to that of cement for the same mass means that the volume of fly ash is about 30 per cent higher than that of cement.

Figure 3 (a) workable CBA/FA mix **Figure 3** (b) CBA/FA mix at high percentage replacement ratio.

Bleeding which is a phenomenon whereby water rises to the surface of freshly mixed concrete due to its lower specific gravity among the constituents of the mix. In this research, bleeding was not physically measured, but it was observed that the process was akin to that of conventional concrete, and this could be attributed to the lower percentage of bottom ash-fly ash replacement to have any significant effect. The rise of water to the top of the mould, and subsequent drying did not last more than an hour even at 20% replacement of both bottom ash & fly ash. There are a number of remedies that have been suggested by researchers on how to overcome excessive bleed, one of which is the application of ultra-fine materials and the use of rounded sand with an excess of 15% passing 150µm (Neville, 95 pp.207)[31].

4.2.2 FIGURES AND TABLES

Compressive strength is a very important parameter in accessing the durability of concrete, and one of the methods of measuring strength is the 28 day cube test. In this research, conventional curing in water method was used and the curing duration extended beyond 28 days to study the effect of pozzolanic reaction; fly ash was used to partially replace cement with no other additional admixture was used. At 28 days, the strength of 15% & 20% replacement were 34MPa and 33.6MPa respectively, which is very close to the targeted strength of 35MPa. Figure 4 shows the result of compressive strength at constant water-cement ratio; overall, all the replacement samples were in the range of above 30MPa which is a good sign. Also, at 7 days, the strength of 5, 10, 15 and 20% replacement samples were within 67% to 79% of the 28 days strength.

In general, concrete with proportion of CBA produce lower strength at the early ages. However, the inclusion of fly ash of equal percentage to CBA to replace cement was responsible for the early age strength increment. It was reported by [40] that most of the furnace bottom ash concrete was lower in compressive strength than the control that was manufactured with natural sand up to an age of 28 days for water – cement ratios of 0.45 and 0.55, but most of the FBA concrete was comparable with that of the control concrete at 365 days.

This can be attributed to three factors which are the hydration of the cement and water at the inception. Nucleation effect occurs as a result of smaller particles of fly ash blending with cement paste to accelerate the reaction and form smaller cementing paste. Lastly, packing effect resulted in denser packing of the material in which fine particles that were not reacted fill in the voids spaces present.

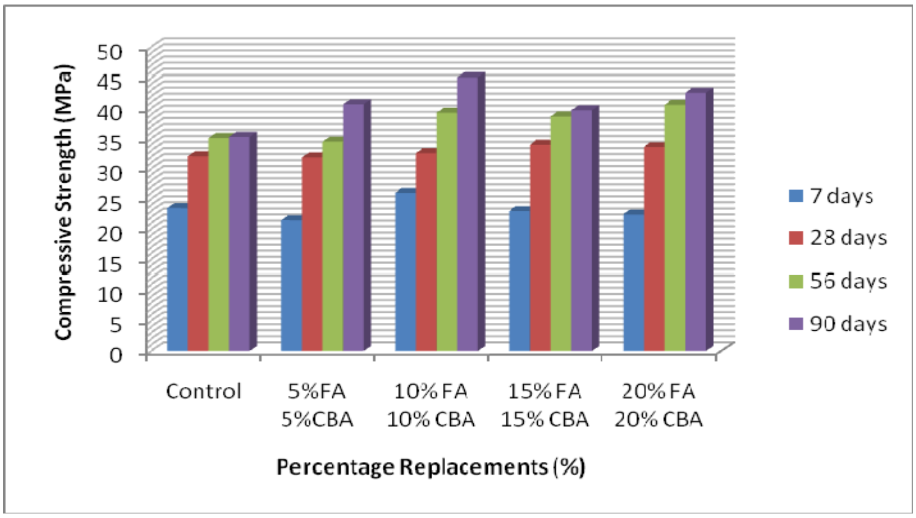

Figure 4: Result of compressive strength for CBA/FA concrete.

In order to have a good, durable concrete, it is good to have gradation of aggregates from large to small, and enough cementing material so as to bind properly. Mechanically, tiny fly ash particles fill voids in concrete due to its hard and round nature, and it also produces a "ball bearing effect" that allows concrete to flow easily into voids.

When the curing age was extended beyond 28 days, all the samples achieved strength above the targeted strength. This can be attributed to the Pozzolanic reaction that normally manifest at a later ages in which $Ca(OH)_2$ reacting with SiO_2 and Al_2O_3 to form C-S-H gel; two materials with pozzolanic properties are present, bottom ash which has been reported to have pozzolanic properties [32] and fly ash, the combination of whom in the presence of lime form cementitious compounds as shown below:

$$C_aO+H_2O \rightarrow Ca(OH)_2 \quad \text{[Eqn. 1]}$$

$$SiO_2+Ca(OH)_2 \rightarrow CaO.SiO_2.\ H_2O \quad \text{[Eqn. 2]}$$

The result of the compressive strength with respect to the percentage increase in strength of the control concrete is presented in table 4. It can be seen that at the age of 90 days curing period, all the replacement samples had strength greater than that of the control sample. This can be attributed to the Pozzolanic reactions that normally manifest at later ages to form C-S-H gel especially in bottom ash; this is a result of larger particles of bottom ash reacting with calcium hydroxide unlike in fly ash that the particle sizes are smaller and reaction is almost immediate.

Table 5: Percentage increase in compressive strength of Concrete samples

Compressive strength (MPa) – Percentage Compressive strength (%)								
Sample marking	7 days		28 days		56 days		90 days	
	MPa	%	MPa	%	MPa	%	MPa	%
Control	23.5	100	32.1	100	35.1	100	35.3	100
5%FA 5%CBA	21.5	91	31.9	99	34.5	98	40.7	115
10%FA 10% CBA	26.0	111	32.6	102	39.3	112	45.1	128
15%FA 15%CBA	23.0	98	34.0	106	38.7	110	39.7	112
20%FA 20%CBA	22.4	95	33.6	105	40.6	116	42.6	121

It should also be noted that keeping the water to cementitious ratio constant at 0.48 was responsible for the strength gain of the concrete, because at higher water-cement ratio, the strength of concrete reduces drastically and vice versa.

The result of the compressive strength was in contrast to what has been reported by many researchers in the literature, it is a widely held believe that the strength development of bottom ash concrete is initially slower at the beginning [3]. However, the strength gain follows the pattern of the control concrete, and this can be attributed to the addition of the fly ash in equal percentage of the bottom ash and also keeping the water - cementitious ratio low because at higher w/c ratio, the strength of concrete decreases drastically. This gives hope that with appropriate replacement ratio, bottom & fly ashes can be utilized in concrete without short and long term durability effects.

The density of the resulting concrete samples with replacement of equal percentage of bottom ash fluctuates at smaller percentages in all curing ages. As the percentage replacements began to increase from 15% to 20%, a decline of density was observed due to lower specific gravity of both fly ash and CBA which conform to the result of [5].

Table 6: Air-dried Density of CBA/FA concrete at 28 days

Sample	Control	5%	10%	15%	20%
(kg/m^3)	2326	2313	2323	2331	2295

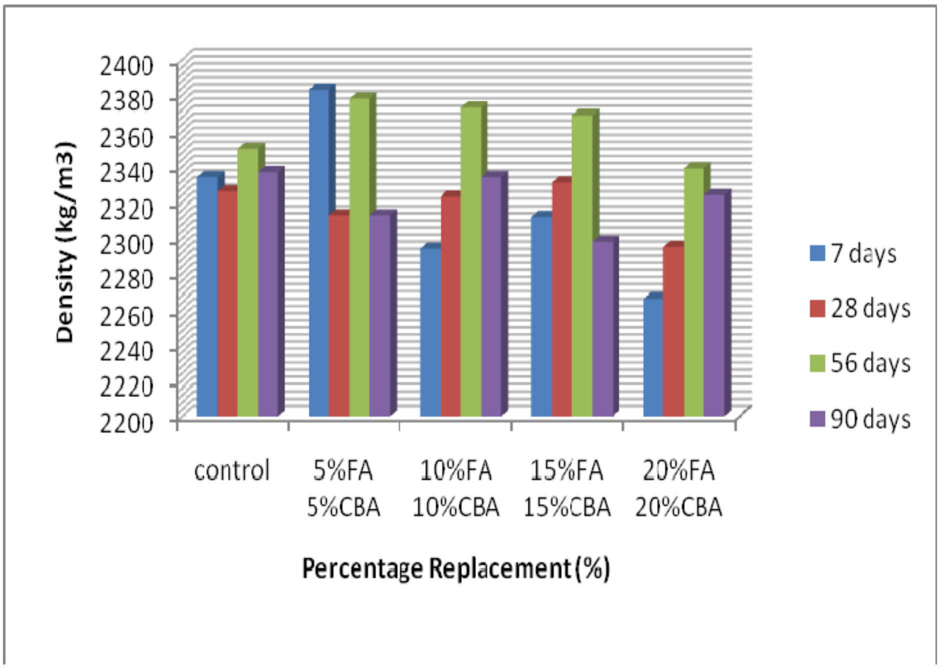

Figure 5: Density of CBA/fly ash concrete at constant w/c ratio.

The density was higher at lower water/cement ratio, because of the cohesiveness of the mix and the bond strength between the cement and aggregate unlike at higher w/c ratio where a considerable amount of water was required to attain the desired workability. Another important factor that might have caused the lower density was the low specific gravity of both bottom ash and fly ash with respect to that of sand and cement, as well as the porosity. The work of [5] reported that the use of lytag, PFA and bottom ash produce a low density at 28 days SSD, and a further decline of density was noticed when they replaced 30% of OPC with fly ash. Therefore, the density of bottom ash – fly ash concrete decreased with an increase of replacement ratio, slightly at the beginning but at higher replacement, drastic decreased is noticed. This is in conformity with Lydon and Balendran (1986) that "the density of concrete increases with the increase in the density of aggregate" (as cited in Neville, 1995, pp 419)[39].

5.0 CONCLUSIONS

The result of the grain size analysis indicated that Tanjung Bin coal bottom ash is distributed from fine gravel to fine sand with a higher percentage of coarse sand particles. The lower specific gravity of fly ash & bottom ash is as a result of the chemical composition which is lower in lime & alumina content (2.45 & 1.9). Tanjung Bin bottom ash aggregate absorbed 19% by weight of dry aggregate in contrast to just 2% of normal weight aggregate and it also indicates that there is a direct relationship between the rate of absorption & time. The workability of the fresh concrete measured in terms of slump and compacting factor decreased as the percentage replacement increases. An increase in curing duration is required to attain maximum compressive strength; the targeted strength was achieved at 56 days curing period for all the percentage replacements. The air-dried density of the concrete showed a marked decline due to low specific gravity of both fly ash and CBA. In conclusion, the use of coal bottom ash and fly ash in concrete has the potential to produce long term durable and good strength concrete. Nevertheless, further research is required on other properties of the CBA/ fly ash concrete.

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Appendix: Grading limits of fine aggregate according to 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