International Journal of Sustainable Construction Engineering & Technology (ISSN: 2180-3242)
Vol 3, Issue 2, 2012

POTENTIAL USE OF MALAYSIAN THERMAL POWER PLANTS COAL BOTTOM ASH IN CONSTRUCTION

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ABSTRACT

As Malaysia focuses its attention to the call for a “greener” culture, so did the engineers and those in the scientific community especially the construction industry who is a major contributor to the depletion of green house gases. The engineering and construction community has now taken up the challenge for the use of “green and recycled by-products” in construction. One of those by-products is the Coal Bottom Ash (CBA) from thermal power plants that faces an increasing production running into hundreds of thousand tonnes in Malaysia alone, and its method of disposal is relegated to landfills alone with no other commercial usage. The construction industry is now forced to rethink on the utilization of the industrial by-products as supplementary materials due to the continuous depletion of natural aggregates in construction. A significant amount of research has been conducted elsewhere on CBA to ascertain its pozzolanic activity, compressive strength in concrete and mortar, durability, water absorption characteristics and density, in order to ensure its usage as a construction material. In this paper, a critical review of the strength characteristics of concrete and mortar as influenced by CBA as partial replacement of fine aggregate is presented based on the available information in the published literatures. Diverse physical and chemical properties of CBA from different power plants in Malaysia are also presented. The influence of different types, amounts and sources of CBA on the strength and bulk density of concrete is discussed. The setting time, workability and consistency as well as the advantages and disadvantages of using CBA in construction materials are also highlighted. An effective utilization of CBA in construction materials will significantly reduce the accumulation of the by-products in landfills and thus reduce environmental pollution.

Keywords: *Coal bottom ash; By-products; Concrete; Mortar; Construction*

1.0 INTRODUCTION

Ever since the Gospel of “Green Culture & Technology” was preached, it spread like “wildfire” consuming everything in its part to the extent that it created a conflict of interest between developed nations and their developing counterparts. Today, a connection has been “presumed” between Climate Change and the CO_2 content of the atmosphere which make it imperative to make use of by-products and low carbon products in the construction industry. The use of recycled & by-products is not only a desire but a necessity. It is interesting to look at this quotation in [1].

“Climate change has created a concern that pervades industrial and research thinking in the industrialized countries, since it presumes a casual relation between human industrial activities and changing climate. In other parts of the world, typically India and China, development of their economy seem to rank as high as concern over climate changes caused by human activities. Thus a conflict is created.”

Malaysia in its effort to promote National Green Technology Policy, has established a Green Technology Council that is aimed at coordinating ministries, agencies, the private sector and key stakeholders to lead to the implementation of the Green Technology Roadmap headed by the Prime Minister himself. In his budget speech of 2010, Prime Minister Najib Tun Abdul Razak announced measures to promote the use of environmentally friendly technology and resources in construction, including the establishment of a RM 1.5bn ($440m) fund for soft loans to companies that use and supply green technology. Thus, Malaysia is set to become the largest green construction sector in the South-east Asian region [2].

The above mentioned initiatives are as a result of the rising demand for energy from the economy and the call for a clean technology. In the electricity industry, Gas remains the main fuel source for the generation industry, but Coal is gaining favour. Gas-fired power plants make up almost 64% of all installed generating capacity; however, coal is growing in the generation fuel mix, rising from 11% in 2002, 26.7% in 2006 & 31% in 2008. The commissioning of two coal fired-power plants in 2009 means that coal use will continue to gain popularity [2]. The energy supplier has argued that coal is the only viable fuel option in terms of cost and supply. It is projected that the installed capacity on the coal power plants in the year 2010 will be 7,200MW (about 40% of the total) requiring about 22.5 million tonnes of coal, that is for 8,200MW capacities [3].

2.0 PRODUCTION OF COAL BOTTOM ASH

When pulverized coal is burned in a dry bottom boiler, about 80 to 90% of the unburned material or ash is entrained in the flue gas and is captured and recovered as Fly ash. The remaining 10 - 20% of the ash is dry Bottom ash, a dark grey, granular, porous, predominantly sand size material that is collected in water-filled hoppers at the bottom of the furnace. In wet bottom boilers, bottom ash is kept in a molten state and collected when it flows into the ash hopper below. The water in the hopper immediately fractures the molten material into crystallized pellets. In this case, the bottom ash is referred to as Boiler Slag (also known as "black beauty") a hard, black, glassy material. The remaining combustion products exit along with the flue gases, the figure below shows the combustion of coal to generate bottom ash in a thermal power plant.

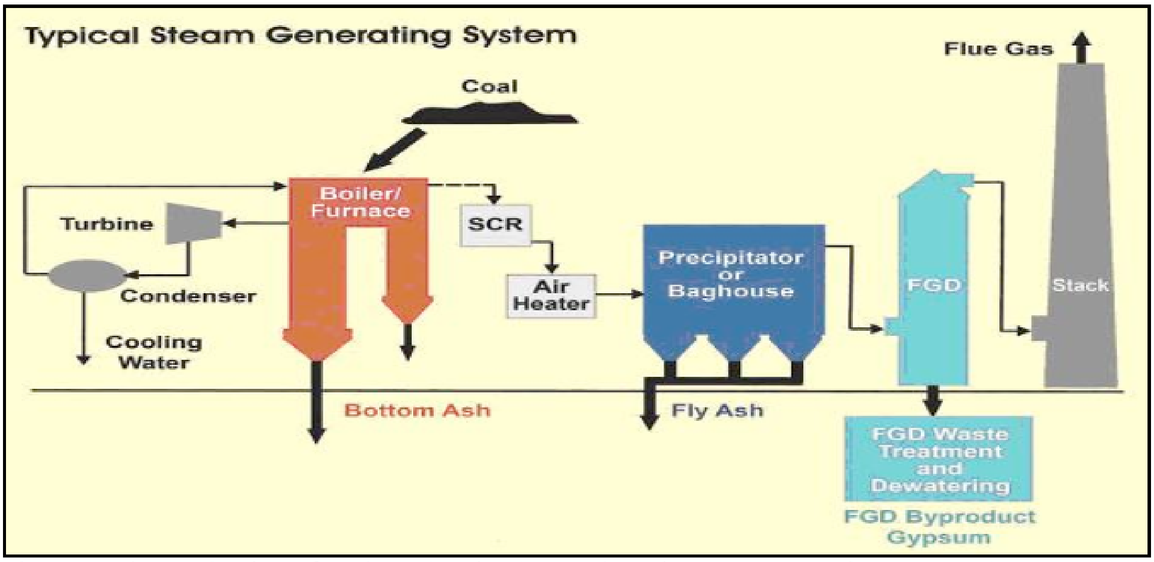


Figure 1: Typical thermal power plant & resulting waste generated
Source: NETL, 2006

The resulting coal ash generated is deposited either in a dry landfill over a vast area of land which is not possible in urban areas or deposited in an ash pond which also has its shortcomings. In Sejingkat Coal Fired Power Station, Kuching Sarawak, fly ash and bottom ash are deposited off into an 81,000m^2 area, 2.4m deep ash pond situated besides the power station. In fact, currently, there are two ash ponds with one of them fully utilized [4]. Tanjung Bin power station produce 180 tonnes per day of bottom ash and 1,620 tonnes per day of fly ash from 18,000 tonnes per day of coal burning alone [5]. The disposal of coal ash has reached an alarming proportion such that its use in construction is a necessity than a desire and if applied on a large scale, would revolutionize the construction industry, by economizing the construction cost and decreasing the ash content.

A report by American Coal Ash Association in 2008 presented in table 1 below showed that the utilization of coal bottom ash has been largely in the area of structural fill & embankment application. There is a relatively low application as blended cement due to its larger size particles & low pozzolanic properties until it has been ground to finer size particles [6] "… the compressive strength of mortar containing bottom ash at an early age depends on its fineness since the chemical composition of original & ground bottom ash are almost the same". Road base in pavement engineering, concrete, grout & aggregate has been the areas with the wider application.

Table 1: Utilization of bottom ash in tones

Application	Bottom ash (tonnes)
Concrete / concrete prod. /grout	720,948
Blended cement / raw feeder for clinker	610,194
Structural fill / embankment	2, 996, 388
Road bases / sub-bases	767, 013
Aggregate	727,048

Source: ACAA,2008

The methods of disposal have its disadvantages in the sense that when the pond or landfill site is not lined with concrete, heavy metals tends to leach into natural ground water and cause contamination. Recently, the disposal in an ash pond has come under heavy criticism with the 2008 collapse of one of the retaining walls at the Tennessee Valley Authority's Kingston power plant that released over a billion gallons of water & coal combustion ash slurry.

Results reported in literature are encouraging concerning the use of bottom ash as a partial or total fine aggregate replacement for natural sand [7]. It should also be noted that CBA is a highly porous material; therefore water absorption will have effect on the workability of the concrete. This paper intends to present discussion on the literature studies done on using CBA as a replacement for natural sand in concrete and mortar.

3.0 CHARACTERIZATION OF COAL BOTTOM ASH FROM DIFFERENT POWER PLANTS IN MALAYSIA

3.1 PHYSICAL PROPERTIES

Laboratory investigations carried out by [8] showed that bottom ashes have 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. Bottom ash is sand sized, usually 50-90% passing a 4.75mm (No. 4) sieve. It also has 10 - 60% passing a 0.42mm (No. 40) sieve, 0 - 10% passing a 0.075mm (No. 200) sieve, and a top size usually above 19mm. For categorization given in BS 882: 1992 based on percentage passing the 600µm sieve, between 55% to 100% would defined it as fine sand. The grading requirements for fine aggregates has been described into four zones in BS 882: 1973 and it was done based on the percentage passing the 600µm (No. 30 ASTM) sieve. The main reason for this is that large number of natural sands divides them at just that size, the grading above and below being approximately uniform [9]. Figure 2, shows a sample of coal bottom ash collected from a power plant.

Figure 2: Bottom ash (University of Kentucky, 2006)

From the study of [10] Wash Bottom Ash has percentage passing 600µm of 58.99%, therefore is considered as fine sand. The calculated fineness modulus of bottom ash is 3.65 which is more than 3.5 and is considered to be very coarse. It was reported by [11] when they performed sieve analysis on three different power plants bottom ash in West Virginia that the percentage passing the No. 4 (4.75mm) ASTM sieve size ranges from 90% - 52% which is in accordance with BS 882: 1992.

Table 2: Grain size analysis from different power plants

	Bottom Ash		
Sieve Size	**Glasgow, WV**	**New Haven, WV**	**Moundsville, WV**
38 mm (1-1/2 in)	100	99	100
19 mm (3/4 in)	100	95	100
9.5 mm (3/8 in)	100	87	73
4.75 mm (No. 4)	90	77	52
2.36 mm (No. 8)	80	57	32
1.18 mm (No. 16)	72	42	17
0.60 mm (No. 30)	65	29	10
0.30 mm (No. 50)	56	19	5
0.15 mm (No. 100)	35	15	2
0.075 mm (No. 200)	9	4	1

Source: Moulton & Lyle, 1973

Result of Sieve analysis by [8] showed that bottom ashes have 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 distribution may be encountered in ash samples taken from the same power plant at different times.

The figure (3) below is a plot of the grading analysis of three different power plants in Malaysia by [12]. Result from Tanjung Bin showed that it is distributed from fine gravel to fine sand, while Kapar and Manjung has a distribution from coarse-medium sand to fine sand, and majority of the sizes ranges between 10mm – 0.075mm. The work of [5] when they performed a sieve analysis on two bottom ash specimens, reported that the specimens were quite similar and exhibit well graded distribution. Their sizes ranging from fine gravel to fine sand sizes and the majority sizes occurred in a range between 20mm and 0.075mm.

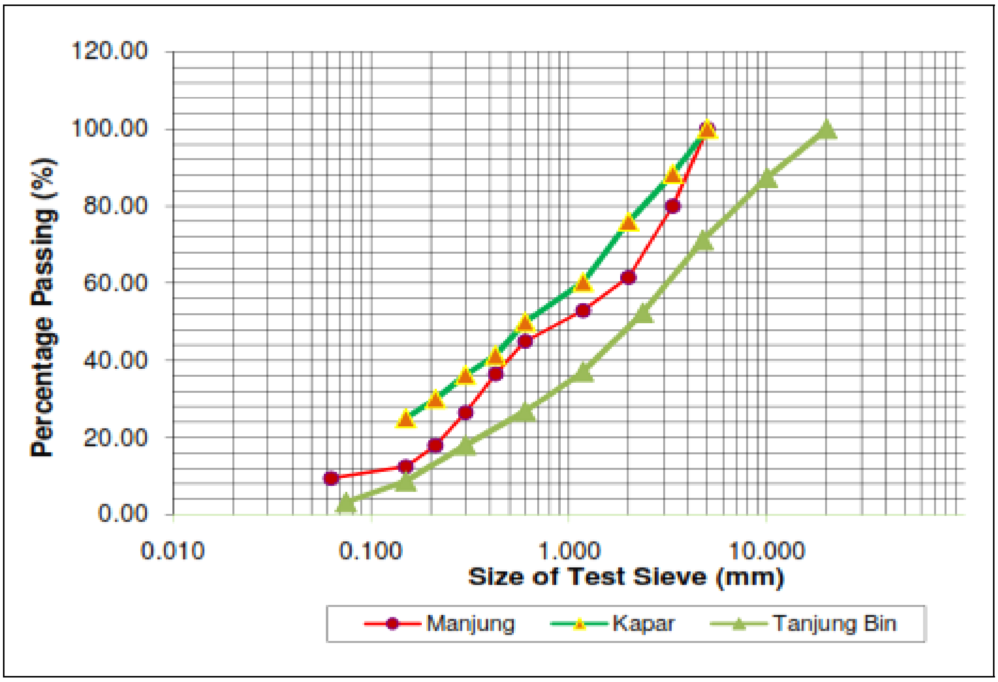


Figure 3: Sieve analysis of Malaysian power plants CBA
Source: Abdul Talib, 2010

Specific gravity of bottom ash is a function of chemical composition, with higher carbon content resulting in lower specific gravity. Coal Bottom ash with a low specific gravity, has a porous or vesicular texture, a characteristics of popcorn particles that readily degrade under loading or compaction [13]. Bottom ash with a porous or hollow ash may present a specific gravity as low as or even lower than 1.6 [14]. The range of the specific gravity of this bottom ash might be different depending on coal type, origin, size, handling, processing technique, boiler size, disposal and storage methods or other criteria [15]. All these factors mentioned have a commanding influence on the specific gravity property of bottom ash, as reported by [16], when they investigated the physical properties of bottom ash specimen taken from different disposal points in a disposal pond. "There is a difference of Gs between the sample taken from nearest to slurry disposal point and one taken farther away".

Kapar bottom ash seems to display lower specific gravity of 2.01 [12]. The lower specific gravity of the bottom ash is due to its chemical composition which is low in Iron oxide content and display of vesicular texture. The specific gravity value is directly proportional to iron content but for lime content greater than 15%, the value is more irrespective of the iron content [17]. Another factor that has an influence on specific gravity is the state of the material, the specific gravity of a dry bottom ash ranges from 2.0-2.6 with an average of 2.35 while wet bottom ash ranges from 2.6-2.9 with an average of 2.75 [14].

3.2 CHEMICAL PROPERTIES

The chemical analysis of CBA either using X-ray energy dispersive spectrometry (EDS) or X-ray fluorescence (XRF) will reveal that the main chemical compounds include Silicates (SiO_3), Aluminates (Al_2O_3) & Iron oxide (Fe_2O_3) with a host of other compounds in smaller percentages. The results of chemical composition analysis conducted on three thermal power stations bottom ash in Malaysia namely Kapar thermal power station in Selangor, Jimah Power plant in Negeri Sembilan and Tanjung Bin in Johor is presented in table 3 from independent researches.

Table 3: Chemical analysis results from different power plants in Malaysia.

	Bottom ash percentages		
	Muhardi et al., (2010)	Fawzan (2010)	Naganathan et al., (2012)
Chemical contents	Tanjung Bin Power Plant	Jimah Power Plant	Kapar power Plant
SiO_2	42.7	49.4	9.78
Al_2O_3	23.0	22.3	20.75
Fe_2O_3	17.0	13.7	37.1
CaO	9.80	9.0	11.1
K_2O	0.96	1.00	-
TiO_2	1.64	2.2	-
MgO	1.54	0.87	3.2
P_2O_5	1.04	0.65	-
Na_2O	0.29	0.13	-
SO_3	1.22	0.68	-
BaO	0.19	-	-
MnO	-	0.08	-
ZnO	-	-	1.8

The major components of the three thermal power plants in Malaysia studied by [5, 18, and 19] were Silica, Alumina & Iron oxide with percentage compositions of 9.78 - 49.4%, 20.75 - 23% & 17 - 37.1% respectively. The bottom ash used by [5,18] 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 [19] 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. The SO_3 content for the both Class F bottom ash of [5, 18] were 1.22% & 0.68% both of which are less than 2.5% specified by BS 3892: Part 1: 1993. The alkali K_2O & Na_2O which are insoluble residue were recorded as 0.96% & 1.00% and 0.29% & 0.13% respectively less than the 1.5% reported by ASTM C 618 – 94a. The result of Class C bottom ash of [19] did not present values for SO_3, K_2O & Na_2O respectively. A research conducted by [20] reported that "In bituminous coal, three major components 'SiO_2, Al_2O_3, Fe_2O_3' accounted for about 90% of the total components whereas lignite or sub bituminous coal ashes had relatively higher percentages of CaO, MgO & SO_3.

4.0 INFLUENCE OF COAL BOTTOM ASH ON THE MECHANICAL PROPERTIES OF CONCRETE & MORTAR

The strength of concrete is influenced by the volume of all voids in it and considering the fact that we are dealing with a very porous material (bottom ash), then it is only natural that we see a decrease in strength properties and unit weight of the resulting concrete. According to [6], "Bottom ash has a large particle size and a high porous surface, resulting in higher water requirement and lower compressive strength". The water retention capacity of bottom ash has also been highlighted by [21] & [22] that "additions increase the capacity of aerated block to retain water since Bottom ash is a porous material, thereby improving the moisture transport behavior within the block during fire". This implies that the water retention property of bottom ash is an advantage during fire functioning as a reservoir.

4.1 SETTING TIME & CONSISTENCY

Setting refers to the stiffening of the cement paste, a change from liquid to a rigid stage [9]. It is equally important to differentiate between setting and hardening which by definition refers to the gain of strength of a cement paste. A minimum time of 60 minutes is prescribed by ENV 197-1: 1992 for cements with strengths up to 42.5MPa and ASTM C 150-94 prescribes a minimum time for the initial set of 45 minutes using Vicat apparatus. The European Standards (EN 450-1, 2005) require the initial setting time of fly ash paste should be at most 120 minutes longer than that of the reference without ash.

Consistency on the other hand for any given cement, is the water content which will produce a paste of standard consistency [23].The test is also prescribed by EN 196-3: 1987. The water content of the standard paste is expressed as a percentage by mass of the dry cement, the usual range of values being in the range of 26-33%. According to [6], when they investigated the development of bottom ash as pozzolanic material by grinding the bottom ash to a smaller particle size, found that the normal consistency of the cement paste was 24.9% while that of the original and ground bottom ash was between 24.7%-25.3%. This is within the limit specified by EN 196-3: 1987.

Studies have identified that the addition of bottom ash to cement materials increases the initial and final setting time in relation to the reference mix [24]. This is due to the increase in quantity of water present in the mixes with bottom ash, resulting in the maintenance of a greater workability, consequently, increasing the time that the mix is in the fresh state. The use of original and ground bottom ash to replace Portland cement has being found to slightly retard the setting times of the paste as reported by [6]. They found that the setting times of cement paste were 112 & 180 minutes for the initial and final setting times respectively. The original and ground bottom ash initial setting times were between 122 minutes and 135 minutes while the final setting times were between 195 minutes and 210 minutes. They attributed the delay in the setting times to the replacement of bottom ash with cement which reduce the quantity of C_3S in the paste.

In [21], it was reported that the setting time of blocks made completely with and without recycled material. The initial and final setting times of the block without bottom ash and fly ash were 47 minutes & 291 minutes respectively while that of blocks with recycle material completely was 152 minutes and 1502 minutes for initial & final setting times respectively. The result showed that the initial setting time was longer by 105 minutes and therefore the limit of EN 450-1, 2005 is not exceeded.

In [25], it has been reported on the effects of natural Pozzolan on properties of cement mortars that “Setting properties of cement matrix were affected by natural Pozzolan ratio substituted for cement. Experimental results show a proportional delay in the initial set time, depending on the natural Pozzolan addition ratio”. This implies that natural Pozzolan decrease rate of hydration by decreasing heat of hydration.

4.2 WORKABILITY & FLOW OF BOTTOM ASH

According to [9], defining workability as “ease of placement and the resistance to segregation” is too loose a description of this vital property of concrete. Workability should be defined as a physical property of concrete without reference to the circumstances of a particular type of construction. The most important factor affecting workability is the water content of the mix, if the water content and other factors are fixed, workability is governed by the maximum size of the aggregate, its grading, shape and texture.

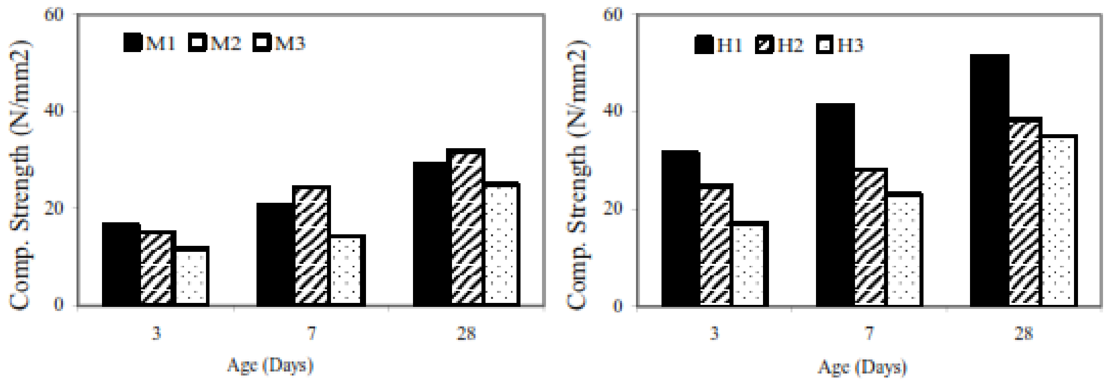
Coal bottom ash has been reported to have a porous texture and angular shape, therefore it will require a considerable amount of water to produce a workable mix and bearing in mind that strength of concrete depends on the water-cement ratio, the higher the w/c ratio the lower the strength of the concrete. Its angular structure has been one of the factors that is restricting it application as reported by [26 - 27] “recycling of bottom ash in construction is restricted for the following reasons; the ash has angular structural characteristics, contains unburned carbon particles”. In [28], they also concur that “A close examination of bottom ash reveals that it has a rough surface texture and is comprised of angular and porous particles. The irregular and angular shape and very porous surface necessitated the use of a higher water content to achieve the degree of lubrication needed for a workable mix”

With respect to mortar, the same observation was made that the flow of mortar decreased when bottom ash is used as fine aggregates. The flow of fresh mortar and workability of concrete are mainly related to size and shape of aggregate particles. The demand for the additional water is increased due to fine particle sizes, amounts and the internal water content of the bottom ash that is stored in the pores structures. Adequate considerations should be given to aspect of water demand in the mix design of bottom ash concrete

4.3 INFLUENCE OF STRENGTH AND BULK DENSITY ON CONCRETE & MORTAR

The mechanical strength of hardened cement is the property of the material that is perhaps most obviously required for structural use [9]. The strength of mortar or concrete depends on the cohesion of the cement paste, on its adhesion to the aggregate particles, and to a certain extent on the strength of the aggregate itself. In this section, the strength of concrete and mortar samples made with different percentages of coal bottom ash will be discussed.

According to [29], large size (greater than 6mm) bottom ash can be used as coarse aggregate and small size can be used as fine aggregate. Also, [30] showed that it is possible to manufacture lightweight concrete (LWC) with Saturated Surface Dry (SSD) in the range of 1560-1960kg/m^3 and a 28 day compressive strength in the range of 20-40 N/mm^2. The test was conducted in two series M (design strength of 20 N/mm^2) and H (design strength of 40 N/mm^2). For series H, compressive strength decreased at all ages, but for M, the decrease was only observed at 3 day strength. There was an increase in strength at 7 & 28 days when natural sand and coarse aggregates were replaced (see figure below).



(a) Series M (b) Series H

Figure 4: Compressive strength for M & H series
Source: Bai, Ibrahim & Basheer, 2010

M1, H1 – Control
M2, H2 – 100% OPC + 100% FBA + 100% LG
M3, H3 – 70% OPC + 100% FBA + 100% LG

They also observed that the density of hardened concrete at SSD condition measured at 28 days indicated a significant reduction in the density of the hardened concrete for both series. When they further replaced 30% of OPC with fly ash, the density of the resulting concrete was further decreased, this they attributed to the low density of fly ash compared to that of OPC.

Table 4: Density of hardened concrete at 28 days (SSD)

M1	M2	M3	H1	H2	H3
1977	1725	1559	2471	1952	1819

Source: Bai, Ibrahim & Basheer, 2010)

As Observed in [28], the strength development for bottom ash concretes follows the pattern of strength gain of the control concrete. However, as they noted, the gain was initially slower than that of the control sample; "….at the end of 60 days curing, an additional gain of 7% was recorded and after 90 day curing, a 13.7% increase in strength over that at 28day was observed". Also, [31] observed that the range of compressive strength of bottom ash mixture was between 4.2-12.5MPa compared to 15.9MPa of the control mix at the age of 3 days for CRT3 and 16.1-21.2MPa for CRT4. When the curing period was extended to 28 days CRT3 recorded 8.6-23.2MPa and control of 28.4MPa while CRT4 26.1-32.6MPa. At the age of 90 days, CRT3 was in the range of 12.5-25.7MPa with the control at 32MPa and CRT4 32.1-38.4MPa.

Table 5: Results of compressive strength & density at different ages of bottom ash

Concrete	**Fresh density (kg/m^3)**	**Compressive strength (MPa)**		
		3 days	**28 days**	**90 days**
0% CRT	2238	15.9	28.4	32.0
25% CRT3	2177	12.5	23.2	25.7
50% CRT3	2090	9.9	18.0	23.0
75% CRT3	1964	6.3	11.5	14.9
100% CRT3	1869	4.2	8.6	12.5
25% CRT4	2220	19.5	27.2	32.1
50% CRT4	2138	17.0	28.5	35.9
75% CRT4	2109	16.1	26.1	32.7
100% CRT4	2040	21.2	32.6	38.4

Source: Andrade et al., 2008

The work of [21] showed that the result of flexural strength for blocks with percentage replacements of bottom ash follows the same trend as that of the compressive strength. The bottom ash was replaced with fine aggregate in percentage replacements of 20 % & 30% respectively. The control block had a flexural strength of 4.4 MPa, while the bottom ash blocks had 3.3MPa & 3.1MPa respectively for 20 & 30 percent replacement levels, which is consistent with the result of the compressive strength where the control block had a strength that is twice that of the 20% bottom ash block. In general, the higher the bottom ash percentage in the block resulted in lower compressive and flexural strength developed as well as the density of the resulting blocks.

Table 6: Variation of density, compressive & flexural strengths of bottom ash blocks

Mixture	Density (kg/m^3)	Rc (MPa)	Rf (MPa)
H0 (control)	2090	22.7	4.4
H-BA20	1740	11.6	3.3
H-BA30	1660	8.2	3.1

Source: Arenas et al., 2011

In terms of the splitting tensile strength of concrete, [28] observed that no reduction in splitting tensile strength as compared to that of the equivalent conventional specimens as long as minimum cement content of 365kg/m^3 is utilized. The inclusion of bottom ash had more influence on tensile strength than compressive resistance. This observation is in agreement with the original hypothesis of conventional concrete that states the use of alternate materials affects tensile strength differently than compressive strength.

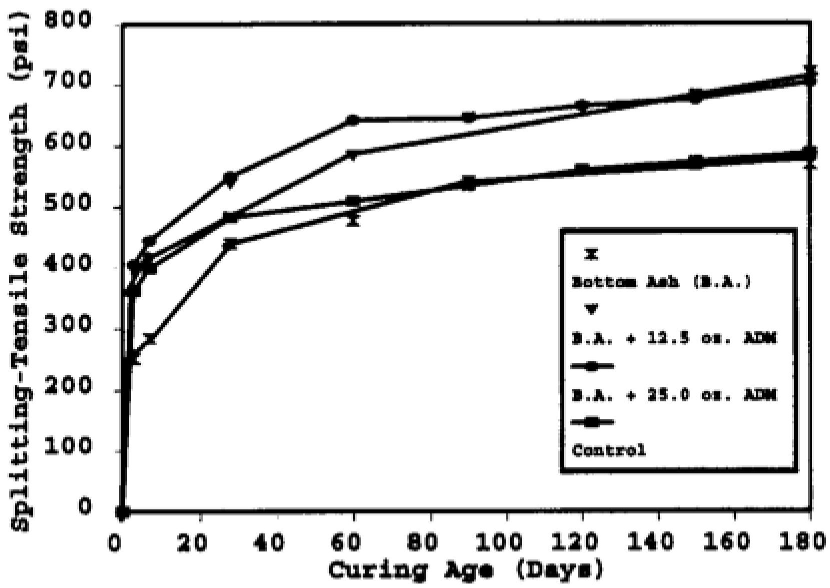


Figure 5: Splitting – tensile strength of concrete containing 600lb/yd^3 (365kg/m^3) cement

Source: Ghafoori & Bucholc, 1996

According to [28], they opined that "In as much as the bottom ash concrete displayed an identical, and in some cases superior, splitting-tensile strength compared to the control mixes, the use of a water-reducing admixture was not necessary for the improvement of the splitting-tensile strength of the bottom ash concrete." Their work consisted of the use of a water reducing admixtures in an attempt to reduce the water – cement ratio.

The strength of mortar composed of coal bottom ash has been found to be affected by a number of factors such as, curing period & the percentage composition. The amount of water has an influence on the strength properties of mortar and concrete. It was reported in [19] that "strength is mainly dependent on the mixing ratio and the water contained" when they investigated the development of brick using thermal power plant bottom ash & fly ash. If excessive water is used, then the strength will decrease [32]. They observed that the more cement used, resulted in high compressive strength, the strength was highest for a mix with water-cement (w/c) content of 412.0/208 and lowest for 386.7/79.4 which had the lowest cement used. The strength of bricks developed at 28 days ranged from 4.3MPa to 10.96MPa. According to [33], "the minimum strength for class 1 brick is 6.9MPa", therefore the bricks developed by [19] is comparable to that of normal clay bricks. They also noted that the density varied from 1500-1650kg/m^3, the relationship between fresh density and water-powder ratio (w/p) indicated that increasing the w/p ratio increases the density of the mix.

5.0 ADVANTAGES OF USING COAL BOTTOM ASH

The use of coal combustion by-products in construction has been shown to provide alternative solutions to the problems of global warming and the depletion of greenhouse gases as well as providing a sustainable future in the use of green and recycled products. The following are some of the benefits that would be derived from the sustained use of coal bottom ash in construction when proper and established standards have been set.

1. It is possible to produce lightweight concrete with a density in the range of 1560-1960 kg/m^3 and a 28 day compressive strength in the range of 20-40 N/mm^2 [30]. Though, the strength development is slow at the beginning but with extended curing days, maximum strength can be achieved.
2. Bottom ash may be used as a partial replacement of natural aggregates, with finer bottom ash used as sand. The percentage of bottom ash that can be used in a mixture composition depends upon its quality and required strength of the product [34].
3. Inclusion of bottom ash has a more pronounced influence on tensile resistance than on compressive strength, reduction of splitting tensile strength is hardly noticed, as long as a minimum cement content of 365 kg/m^3 is utilized [28].
4. Drying shrinkage decreased with an increase in bottom ash content. Concrete made from bottom ash exhibits a reduced drying shrinkage in comparison with that of the control samples [28].
5. Due to increased demand for mixing water, bottom ash mixture displayed a much higher degree of bleeding than the control concrete [28].
6. High fire resistance: for protection against fire, those materials that retain large quantity of water are more desirable, since when they are exposed to a fire, part of this water evaporates and is transported from the fire exposed surface to the interior of the material, where the water cools and condenses again [35].
7. Fly and bottom ashes increase the fire resistance of blocks, and are principally due to the wide evaporation plateau that those ashes incur as a result of increase water intake of the porous aggregates [21]

6.0 DISADVANTAGES OF USING COAL BOTTOM ASH

The use of coal bottom ash in concrete and mortar production has enormous advantages and potentials in the long run, but there are some shortcomings that have to be overcome.

1. The early strength development of coal bottom ash has been shown to be very slow at the beginning, but as the curing period is extended beyond 28days, a dramatic increase in strength is noticed [6].
2. Bottom ash mixtures display a lower modulus of elasticity than the control mixes. The empirical relationship between static modulus of elasticity, unit weight and compressive strength is slightly lower than that suggested by the American Concrete Institute (a=31.2) [28].
3. Due to high water absorption rate, angular shape and very porous surface of the bottom ash, higher water content is required to achieve the degree of lubrication needed for a workable mix. The increase water demand has a moderate effect on early-age characteristics of bottom ash concretes [28].
4. The inclusion of bottom ash has been shown to delay the setting time of the mixture with increase in percentage of bottom ash, the initial setting time is further delayed. This can be attributed to the reduction in the quantity of C_3S as a result of adding bottom ash and the amount of mixing water required to maintain a workable mix

7.0 CONCLUSIONS AND FUTURE RESEARCH ON COAL BOTTOM ASH

Ten years ago, statistics have shown that the coal consumption by thermal power plants in Malaysia was 11% of the total energy demand of Tenaga Nasional Berhad and it was estimated that by 2010, the energy demand and coal usage will jump to 40% out of which 15-20% of the by-product is bottom ash which at the moment has no commercial application but only left to litter landfills unlike its companion fly ash. The use of coal bottom ash in construction will serve to reduce carbon dioxide emission as a result of cement-based processes; imbibing the culture of green building and technology by a sector that is a major contributor of emissions and reduction of landfills and landfill cost to the government.

Available literatures have shown that the application of coal bottom ash by partially or fully replacing sand in concrete or mortar production in percentage replacements of about 10-30 percent have shown remarkable improvement with a small reduction of strength which can be overcome with a longer curing duration due to the delay of pozzolanic reaction of bottom ash until later ages. Also, contrary to the popular opinion that bottom ash is an inert material, it has been shown that with appropriate percentage replacements, bottom ash can perform better than the reference samples at later ages of curing period due pozzolanic reaction after the initial stages which is relatively slow.

Future research on the use of coal bottom ash in construction should focus on the following:

1. An established set of standards that spells out guidelines on its usage and regulates it if need be.
2. Long-term study on the effect of durability and strength properties of concrete and mortar using coal bottom ash is required.
3. The influence of constituent materials on the water absorption [19].
4. Chloride transport and Corrosion effect of coal bottom ash concrete.

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