Physical and Chemical Properties of Coal Bottom Ash (CBA) from Tanjung Bin Power Plant

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Abstract. The objective of this study is to determine the physical and chemical characteristics of Coal Bottom Ash (CBA) obtained from Tanjung Bin Power Plant Station and compare them with the characteristics of natural river sand (as a replacement of fine aggregates). Bottom ash is the by-product of coal combustion during the electricity generating process. However, excess bottom ash production due to the high production of electricity in Malaysia has caused several environmental problems. Therefore, several tests have been conducted in order to determine the physical and chemical properties of bottom ash such as specific gravity, density, particle size distribution, Scanning Electron Microscopic (SEM) and X-Ray Fluorescence (XRF) in the attempt to produce sustainable material from waste. The results indicated that the natural fine aggregate and coal bottom ash have very different physical and chemical properties. Bottom ash was classified as Class C ash. The porous structure, angular and rough texture of bottom ash affected its specific gravity and particle density. From the tests, it was found that bottom ash is recommended to be used in concrete as a replacement for fine aggregates.

1. Introduction
Malaysia with its developing economy and population which has achieved a figure of 29 million in 2010 is experiencing a continuous, strong increase in its electrical power consumption [1]. In order to keep up with the demand for electricity, the Malaysian government has allowed private investors to develop several large power stations. Tanjung Bin Plant Station is the largest coal fired power plant station in Malaysia which has a generating capacity of 2,100 MW (3 x 700 MW) that started its operation in 2006 [2]. It is the first private coal-fired plant in Malaysia which is also the biggest coal fired power plant in South-East Asia. It is also one of the power plants that uses pulverized coal in the production of electricity other than thermal power plants in Malaysia.

In Malaysia, coal has been identified as an important source of fuel, where it is widely used in the production of electricity, steel and cement manufacturing [3], [4]. According to Abu Bakar et al. [5], even though gas remains as the main fuel source for electricity generation, coal is fast gaining favour. It can be seen that the total consumption in the fuel mix for the production of electricity has
been increasing annually from 14% in 2008, 16% in 2009, 22% in 2010 and 24% in 2011[6]. Coal is a complex combination of organic matter and inorganic mineral matter formed over ions from successive layers of fallen vegetation. Coal can be classified as bituminous or sub-bituminous. However, Tanjung Bin Power Plant was designed to burn up to 30% of sub-bituminous coal which is imported from Indonesia, Australia, China and South Africa where the coal is transported to the power plant jetty via ocean-cargo vessel [7].

Due to the higher demand for electricity generation which has led to a higher production of coal ash, a high amount of industrial waste is produced by power plant stations. Cherif et al. [8] stated that 1.2 million metric tons of coal ash is produced during the combustion of 2.9 million metric tons of coal. According to Muhardi et. al [4], there are various types of coal ash that are produced from coal combustion during the electricity generation process such as fly ash, bottom ash, boiler slag, clinker and etc as shown in Figure 1 [9]. However, the major coal ash waste products that have been produced were fly ash and bottom ash. Since fly ash is the most well-known coal ash combustion product, Han et al. [10] and Singh and Siddique [11] found that fly ash is also known as supplementary cementitious material that is usually used in concrete mixtures as blended cement for increasing the workability and durability of concrete. Meanwhile, coal ash collected at the bottom of a furnace is known as coal bottom ash (CBA) since it is heavier and harder to be carried by flue gas compared to fly ash [9], [12], [13].

However, due to the larger production of coal ash such as fly ash and bottom ash, it has contributed to environmental problems such as contaminating ground and surface water due to limitation of dumping space, where it is still treated as waste and put in impoundment ponds, silos or landfills. According to the Environmental Protection Agency (EPA), living next to a coal ash disposal site can increase human health risk of cancer or other diseases. It can also affect drinking water from a well where humans may get cancer from drinking water contaminated with arsenic [14].

Recently, many studies have shown an interest in exploring bottom ash as a construction material which has brought many benefits to the industry due to its low cost, low density fill and also its suitability to be used as replacement of construction material which make it a very sustainable [9] material. Topçu and Bilir [15] tested non-ground bottom ash as fine aggregate replacement in concrete with various replacement ratios in order to determine the effect of bottom ash on shrinkage cracking and it was found that the increasing content usage of bottom ash till 100% will affect the ratio of shrinkage cracking due to the porous structure. Andrade et al. [16] evaluated the influence of CBA as fine aggregates on the fresh properties of concrete. They found that the presence of bottom ash in concrete has affected the setting time. Besides that, the fresh state was also vulnerable to water loss by bleeding. The higher the percentage of BA used as a fine aggregate replacement, the lower the deformation through plastic shrinkage. Aggarwal et al. [17] investigated the effect of the use of coarse bottom ash as a replacement of fine aggregates on the mechanical properties of concrete and found that the strength development for various percentages of BA can easily be compared to the strength of normal concrete at various curing days.

Overall, bottom ash can be used as fine aggregate replacement in concrete production [18]–[20], as structural fillers, road base material, soil modification and etc [21]. However, there is a lack of research on the basic properties of bottom ash. Therefore, this paper aims to study the physical and chemical properties of coal bottom ash produced by Tanjung Bin Power Plant Station. The particle size distribution, density, specific gravity, microstructure and chemical composition of bottom ash were tested to compare the properties of bottom ash with natural fine aggregates and explore its potential applications in concrete.
2. Materials and Experimental program

The bottom ash used in this study was obtained from Tanjung Bin Power Plant (Coal Power Plant Station) in Pontian, Johor, Malaysia. The bottom ash was produced from different sources of coal from Indonesia, Australia, China and South Africa. The coal ash content in bituminous and sub-bituminous coal was 10-15%, respectively. Coal ash may either settle out in the boiler (bottom ash) or get entrained in the flue gas (fly ash). The effect on particular matter emission rate usually depends on the distribution of coal ash between the bottom ash and fly ash fractions. Besides that, it also depends on the boiler firing method and furnace type (wet or dry bottom). The bottom ash used was dried at oven temperature (110 ± 5°C) for 24 hours to ensure that it is free from any moisture. Next, the particle size distribution was carried out in accordance with ASTM C33 to control the aggregate size using a sieve analysis. The fine bottom ash should be passed through a 5mm sieve (No 4) and retained on a 75μm sieve (No 200) while the coarse bottom ash should be passed through a 20mm sieve and retained at a 10mm sieve as shown in Figure 2. Bottom ash density and specific gravity were evaluated according to the procedures proposed in ASTM C29 (Bulk Density and Voids in Aggregate) and ASTM C128-97 (Specific Gravity and Absorption of Fine Aggregate). Microstructural features and the chemical composition of both natural river sand and bottom ash were studied using X-ray Fluorescence (XRF) and scanning electron microscopy (SEM). In order to evaluate the microstructural and chemical composition, the bottom ash was had to pass a 63μm sieve. Since bottom ash was used as fine aggregate replacement the properties of bottom ash were compared with that of natural river sand.
3. Result and Discussion.

3.1. Characterization of Natural River Sand

Aggregates will normally occupy about 65-80 percent of total concrete volume in a concrete mixture. Hence, two types of aggregates will be used in the concrete mixtures which are fine aggregates and coarse aggregates, respectively. According to ASTM C33 standard specification for concrete aggregate, fine aggregate consists of natural sand, manufactured sand or a combination of natural and manufactured sand while coarse aggregate consists of gravel, crushed gravel, crushed stones and etc. It can also be obtained from waste material that is produced by industrial waste, agricultural waste, construction waste and etc. However, in this research, fine aggregates used originated from natural river sand. From the tests that have been conducted, it was found that natural river sand had a fine texture as well as irregular and angular shapes as shown in Figure 3 and Figure 4. However, from Figure 4, the surface of river sand was apparently compact with some discontinuities and attached smaller particles.

Figure 3. Particle image of natural river sand at 100X magnification.

Figure 4. Particle image of natural river sand at 300X magnification.
3.2. Characterization of Bottom Ash

3.2.1. Size particle distribution
The test for the identification of particle size distribution was conducted by sieving the river sand and bottom ash by using the sieve sizes measuring 10mm, 5mm, 2.36mm, 1.18mm, 600µm, 300µm and 150µm. The particle size distribution of fine aggregates (river sand) and bottom ash were shown in Figure 5. The results showed that the curve is a smooth curve revealing that the particle size distribution of bottom ash were in the range with natural river sand, so it can be a good correlation to show that the bottom ash possess ideal quality thereby enhancing the quality of concrete especially in terms of strength. Besides, it can be observed that bottom ash is a dark gray material that has a grain size similar to coarse to fine grains and part of it was sand-like material. Therefore, in order to recover the size of bottom ash more clearly, SEM tests were conducted.

![Figure 5](image)

**Figure 5.** Particle size distribution between natural river sand and bottom ash.

3.2.2. Density and Specific Gravity
The material density is measured by weight and volume, while the specific gravity of bottom ash was measured using a pycnometer as shown in Figure 6 (a) and (b). As expected, the density values of bottom ash were less than the density of natural river sand. From the analysis, it was found that the density of natural river sand is 1223.78kg/m³ which are slightly higher than the density of bottom ash which is 641.03kg/m³. According to Arenas et al. [22], bottom ash is the best replacement material for natural fine aggregates due to the texture of bottom ash which is glassy, fused and also due to a higher recycling rate. Besides that, some researchers found that bottom ash has the potential to be used as a lightweight aggregate due to its low particle density which is lower than river sand [17]. Meanwhile, the specific gravity of coal bottom ash which is 2.21 is lower than the specific gravity of river sand which is 2.81. Due to the porous structure and popcorn-like particles of bottom ash, the low specific gravity is affected and this causes it to be easily degraded under loading or compaction [23]. From previous studies, the specific gravity of bottom ash is between 1.39-2.66 which differs for each power plant station, meanwhile the specific gravity of coarse aggregates (2.51) is lower than fine aggregates (2.62) [24]. It can be concluded that, the specific gravity of bottom ash were in the range with coarse and fine aggregates.
3.2.3. *Microstructural Characterization*

The microstructures of coal bottom ash were determined by conducting a scanning electron microscope (SEM) test as shown in Figure 7 (a) and (b). By using microscope with a magnifying power of 100X and 300X respectively, the shape of bottom ash particles can be seen more clearly and this makes it easy to make a comparison between river sand particles. Based on Figure 4, note that the appearance of the bottom ash particles is porous, angular and irregular in shape and possesses a rough texture. Some of the particles were spherical whereas there were also popcorn type particles. As shown in Figure 4 (b), the smallest size of bottom ash is 10.05µm which is smaller than river sand which measures 31.25µm.

![Particle size image of bottom ash at 100X magnification.](image)

Figure 7 (a). Particle size image of bottom ash at 100X magnification.
3.2.4. Chemical Composition

The chemical composition of coal bottom ash was determined by using X-ray Fluorescence (XRF). Samples of bottom ash from Tanjung Bin Power Plant were tested. Results show that the oxide composition of natural river sand and coal bottom ash can be identified, namely calcium oxide (CaO), silica (SiO$_2$), alumina (Al$_2$O$_3$), iron oxide (Fe$_2$O$_3$) and iron with small amounts of calcium, magnesium, sulphate and etc. The total composition of chemical properties of SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ present altogether in the coal bottom ash that has been dried in the oven for 24 hours varied from 53.58% to 58.53% and as such the coal bottom ash used in this study conformed to ASTM C 618-03 Class C ash which has a minimum content sum of SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ which is 50%. Since bottom ash was included in class C it has pozzolanic properties and also has some cementitious properties. Besides that, it may also contain lime (CaO) higher than 10%. To produce cementitious mixtures, bottom ash requires a cementing agent such as Portland cement, quicklime or hydrated lime that reacts with water. Meanwhile, the total composition properties of SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ present altogether in the natural river sand is 58.15 %. Table 1 shows the chemical composition between bottom ash and natural river sand. However, the result shows that the silicon oxide content in river sand and bottom ash is 51% and 33.70% respectively. The presence of silicon oxide is essential as it is an important element that is required during the mixing of concrete. But other elements that were found in bottom ash but not in river sand are magnesium oxide (MgO), sodium oxide (Na$_2$O), sulfur trioxide (SO$_3$), phosphorus pentoxide (P$_2$O$_5$) and barium oxide (BaO). Part of these elements were non-flammable compounds, part of them consisted of species that are significant pollutants while some of them were powerful desiccant and dehydrating agents [25],[26].
Table 1. Chemical Composition of Coal Bottom Ash and Natural River Sand.

| Formula (%) | Natural River Sand | Coal Bottom Ash (Tanjung Bin) |
|-------------|--------------------|------------------------------|
| SiO₂        | 51.00              | 33.70                        |
| Al₂O₃       | 6.83               | 12.90                        |
| Fe₂O₃       | 0.32               | 6.98                         |
| CaO         | 0.48               | 6.34                         |
| K₂O         | 0.40               | 1.19                         |
| TiO₂        | 0.58               | 0.89                         |
| MgO         | -                  | 0.65                         |
| SO₃         | -                  | 0.90                         |
| Na₂O        | -                  | 0.59                         |
| P₂O₅        | -                  | 0.30                         |
| BaO         | -                  | 0.22                         |

Conclusion
This research has studied the physical and chemical properties of coal bottom ash obtained from Tanjung Bin Power Plant Station and compared them with those of natural fine aggregates (natural river sand). This is because industrial waste like bottom ash will contribute to the increment in environmental problems such as contaminating ground and surface water due to limitation of dumping space. Therefore, the usage of bottom ash as a substitution for natural fine aggregates will reduce waste, also helps in solving the environmental problems that occur and also make the world greener and more sustainable. However, from the several tests that have been conducted, it was found that the particle size distribution curve between bottom ash and sand was similar even though the grain size of bottom ash was similar to coarse to fine grains and part of it was sand-like material. Unlike natural river sand, bottom ash produced angular and irregular shapes and have rough texture while some of the particles showed spherical shaped and popcorn type particles. Meanwhile, the density of bottom ash is lower than the density of natural river sand as a result of the porous structure of bottom ash. Due to the porous structure, the specific gravity of coal bottom ash which is 2.21 is lower than the specific gravity of river sand which is 2.81. Therefore, it can be concluded that this study shows that natural river sand and bottom ash are very different in terms of physical and chemical properties. However, tests showed that bottom ash is a recommended industrial waste that has the potential to be used in concrete as a replacement of fine aggregates since the physical and chemical properties of bottom ash is almost similar with natural river sand. Besides, from the observation that was made, found that by using this material it is more sustainable and environmentally friendly and also avoids the use of natural resources such as natural sand and gravel. Therefore, further studies are required to explore the applications of bottom ash as construction material.

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References

1. R. Raju, M. M. Paul, and K. A. Aboobacker, 2014, “Strength Performance of Concrete Using Bottom Ash As Fine,” Int. J. Res. Eng. Technol., vol. 2, no. 9, pp. 111–122.
2. A. U. Abubakar and K. S. Baharudin, 2013, “Tanjung Bin Coal Bottom Ash: From Waste to Concrete Material,” Adv. Mater. Res., vol. 705, no. JUNE, pp. 163–168.
3. M. Tiwari, S. K. Sahu, R. C. Bhangare, P. Y. Ajmal, and G. G. Pandit, 2014, “Elemental characterization of coal, fly ash, and bottom ash using an energy dispersive X-ray fluorescence technique,” Appl. Radiat. Isot., vol. 90, pp. 53–7.
4. Muhardi, A. Marto, K. A. Kassim, A. M. Makhtar, foo wei Lee, and shin lim Yap, 2010 “Engineering Characteristics of,” pp. 1117–1129.
5. A. U. Abubakar, K. S. Baharudin, and I. Technology, 2012, “Potential Use of Malaysian Thermal Power Plants,” vol. 3, no. 2, pp. 25–37.
6. IEA (International Energy Agency) Key World Energy statistics (2015)
7. Y. Oka and M.R Embi, 2007, “ Coal-Fired Boiler Plant History for Malaysian Projects”, Challenges of Power Engineering and Environment, Vol.1.
8. M. Cherif, J. C. Rocha, and J. Péra, 1999, “Pozzolanic properties of pulverized coal combustion bottom ash,” Cem. Concr. Res., vol. 29, no. 9, pp. 1387–1391.
9. D. Bajare, G. Bumanis, and L. Upeniece, 2013, “Coal combustion bottom ash as microfiller with pozzolanic properties for traditional concrete,” Procedia Eng., vol. 57, pp. 149–158.
10. M.-C. Han, D. Han, and J.-K. Shin, 2015, “Use of bottom ash and stone dust to make lightweight aggregate,” Constr. Build. Mater., vol. 99, pp. 192–199.
11. M. Singh and R. Siddique, 2016, “Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete,” J. Clean. Prod., vol. 112, pp. 620–630.
12. E. Menéndez, a M. Álvaro, M. T. Hernández, and J. L. Parra, 2014, “New methodology for assessing the environmental burden of cement mortars with partial replacement of coal bottom ash and fly ash,” J. Environ. Manage., vol. 133, pp. 275–283.
13. M. Singh and R. Siddique, 2013, “Effect of coal bottom ash as partial replacement of sand on properties of concrete,” J. Clean. Prod., vol. 112, pp. 620–630.
14. U.S. Environmental Protection Agency (EPA), 2007, “Human and Ecological Risk Assessment of Coal Combustion Wastes‘ (draft). (Released as part of a Notice of Data Availability).
15. I. B. TOPÇU and T. BILIR, 2008, “Effect of Bottom Ash as Fine Aggregate on Shrinkage Cracking of Mortars,” A CI Mater. J.
16. L. B. Andrade, J. C. Rocha, and M. Cherif, 2009, “Influence of coal bottom ash as fine aggregate on fresh properties of concrete,” Constr. Build. Mater., vol. 23, no. 2, pp. 609–614.
17. P. Aggarwal, Y. Aggarwal, and S. M. Gupta, 2007,“Effect of Bottom Ash As Replacement of Fine,” Asian J. Civ. Eng. (Building Housing) Vol., vol. 8, no. 1, pp. 49–62..
18. H. K. Kim and H. K. Lee, 2011, “Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete,” Constr. Build. Mater., vol. 25, no. 2, pp. 1115–1122.
19. M. Singh and R. Siddique, 2014, “compressive strength, drying shrinkage and chemical resistance of concrete incorporating coal bottom ash as partial or total replacement of sand,” J. Clean. Prod., vol. 112, pp. 620–630.
20. M. H. W. Ibrahim, A. F. Hamzah, N. Jamaluddin, P. J. Ramadhansyah, and A. M. Fadzil, 2015, “Split Tensile Strength on Self-compacting Concrete Containing Coal Bottom Ash,” Procedia - Soc. Behav. Sci., vol. 195, pp. 2280–2289.
21. M. Syahrul, M. Sani, F. Muftah, and Z. Muda, 2010 , “The Properties of Special Concrete Using Washed Bottom Ash ( WBA ) as Partial Sand Replacement,” Int. J. Sustain. Constr. Eng. Technol., vol. 1, no. 2, pp. 65–76.
22. C. García Arenas, M. Marrero, C. Leiva, J. Solís-Guzmán, and L. F. Vilches Arenas, 2011, “High fire resistance in blocks containing coal combustion fly ashes and bottom ash,” *Waste Manag.*, vol. 31, no. 8, pp. 1783–1789.

23. C.W Lovell, W.H. Huang, and J.E. Lovell, 1991 “Bottom ash as highway material” Presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C.

24. L. B. Andrade, J. C. Rocha, and M. Cheriaf, 2007 “Evaluation of concrete incorporating bottom ash as a natural aggregates replacement,” *Waste Manag.*, vol. 27, no. 9, pp. 1190–1199.

25. Greenwood, Norman N.; Earnshaw, Alan, 1997. Chemistry of the Elements (2nd ed.). Butterworth-Heinemann.

26. Taurian, O. E.; Springborg, M.; Christensen, N. E, 1985, ” Self-consistent electronic structures of MgO and SrO” *Solid State Communications*, Volume 55, Issue 4, p. 351-355.