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Original Research Article

Study on The Mechanical Properties of Bottom ASH as a Partial Sand Replacement in a Non-Load Bearing Fly ASH Bricks

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Abstract

The worldwide production of coal ashes is estimated to more than 800 million tonnes in 2012. Coal use is forecast to rise over 50% to 2030, with developing countries responsible for 97% of this increase worldwide. The estimated worldwide production of coal ashes is around 13.33 billion tonnes in 2030. The reuse rate for fly ash is around 47% whereas the reuse of bottom ash is only around 5.28%. It has contributed to environmental problems such as contaminating ground and surface water due to the limitation of dumping space, where it is still treated as waste and put in impoundment ponds, silos or landfills. By using Coal waste to replace cement production, the environmental benefits will occur and lead to a decrease in CO_2 emissions by 0.9 tonnes for each ton of fly Ash used. According to the Environmental Protection Agency (EPA), living next to a coal ash disposal site can increase the 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. In Malaysia, there is seven coal-fired electric power station for the time being. In Peninsular Malaysia, there is four coal-fired electric power station that produced at least 1400 MW of electric power. Coal waste is produced which includes coal ash in the fraction of about 75-85 % Fly Ash (FA) and 15-25 % Bottom Ash (BA). The study was conducted using the waste products from Tanjung Bin power plant which located in Mukim Serkat, Daerah Pontian, Johor, Malaysia that started operation in September 2006 with a capacity of (2100MW) electricity generating capacity. It is one of the four thermal power plants that utilize pulverized coal in the generation of electricity. Tanjung Bin power station produces 180 tonnes per day of bottom ash and 1,620 tonnes per day of fly ash from 18,000 tonnes per day of coal. This study presents the results of an experimental investigation on the probability of using Bottom-ash products in producing Fly-Ash bricks. By substituting 20% of cement with FA and fine aggregate (river sand) with partial replacement of 5%,10%,15% and 20% of BA where sand replacement can save the natural sand resources from depletion and also reduce the coal ash (CA) in Malaysia which classified under the Scheduled Waste (SW 104) Environmental Quality Act. The results of compressive strength at 7,14 & 28 days of air curing showed that the compressive strength and flexural strength decrease with the increasing of sand replacement of the bottom ash while noticed a visible increment of the water absorption ratio with increasing BA percentage wheras density shows the opposite of that.
Keywords: Fly ash brick, coal ash, bottom ash, sand & cement replacement, mechanical properties.

INTRODUCTION

Sustainable development is defined as "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs". The three main aspects of sustainable development are economy, environment and social community. One of the key factors in sustainable development is the three R's rules, which indicated as Reduce, Reuse and Recycle. The reuses of engineering waste materials such as coal combustion by-products in civil engineering works have become the trend recently [1].

As a result of development and fast growing in Malaysia lately, Malaysia encounters depletion of natural resources of sand. There are two types of sources that sand mined from, terrestrial and marine deposits. The most common terrestrial sources are river channel deposits, floodplain alluvial deposits and residual soil deposits; the marine sources are the shore and offshore deposits. In Malaysia, the main source of sand is from in-stream mining as Kelantan River mining activities where There are approximately 128 sand mining operations along the Kelantan River from Kuala Krai to Tumpat [2]. The sand mining activities in Malaysian rivers have created several environmental problems, such as the deterioration of river water quality, bank erosion, river bed degradation, buffer zone encroachment, destruction of aquatic habitats by bed degradation, lower water levels and channel degradation which affect the aquatic ecosystem.

Coal is one of the world's most important sources of energy, fuelling almost 40% of electricity worldwide. In 2016, the amount of CCPs produced in European (EU-15) power plants totalled 40 million tonnes according to ECOBA statistics. In India, coal-fired Plants produce around 100 ton of ash [3].

Malaysia produces about 8.5 million tons of coal ash as waste which comprises of bottom ash (1.7) million tones and fly ash (6.8) M tones generating the electricity since 1988. The coal powered power plants in Malaysia presented in Table-1 [4]. When pulverized coal is burned in a dry bottom boiler, about 70- 85% of the unburned material or ash is entrained in the flue gas and is captured and recovered as Fly ash that channelled into the pipe gases and later extracted by electronic precipitators. The remaining 15 - 25% of the ash is dry Bottom ash will accumulate from the combustion compartment as coarser material. The production of this waste is increasing tremendously over the years as a result of replacing gas-fired plants in Malaysia by coal combustion power plant [5].

Table-1: Coal-fired plants in Malaysia

Power plant	Commissioning year	Capacity (MW)
Jimah, Negri Sembilan	2009	1400
Manjung, Perak	2002	2295
Kapar, Selangor	1988	2420
Tanjung Bin, Johor	2006	2100
Mukah, Sarawak	2009	270
PPLS, Sarawak	2006	110
Seijngakt, Sarawak	1997	100

Generally, FA is a fine-grained material; its Sizes may vary from less than 10µm to more than 100 µm and density of individual particles from less than 1Mg/m3 hollow spheres to more than 3 mg/m3 (ACI Committee 232). Bottom ash, on the other hand, has angular particles with a very porous surface texture [6]. Its particle size is ranging from 0.06 mm to 20 mm. However, more than 90 % of BA has a size of less than 6 mm. The BA, therefore, is a coarse-grained material and would have the properties of sandy material. 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 [7]. The particle size distribution and appearance of BA are comparable to that of river sand. BA is comprised of mostly silica, iron and alumina, a trace amount of sulphate, magnesium, calcium, etc. These chemical constituents in and grading of BA make it more feasible for the production of concrete, and we replace our sand partially with it. Cement is also partially replaced by 20% by fly ash as its size and properties near to Portland Cement properties. BA and FA are by-products of pulverized coal combustion. Using them together, increase the use of disposal wastes which can reduce the environmental impact.

METHODOLOGY

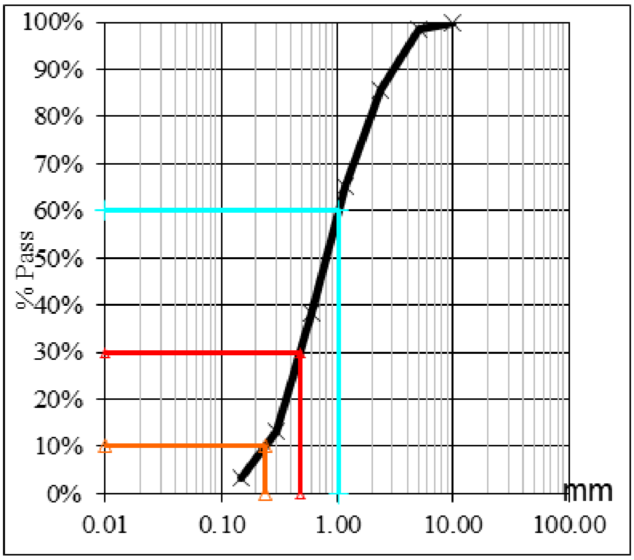
MATERIALS

OPC

Ordinary Portland cement used in this study is ORANG KUAT branded OPC which is a product from one of the largest cement manufacturers in Malaysia, YTL Cement Sdn. Bhd. The physical properties of ORANG KUAT OPC is specific gravity of 3.15 (density = 3150 kg/m3) and fineness = 3170cm2/g. Other than these properties, ORANG KUAT OPC also in compliance with the Malaysian Standard of MS 522: Part 1: 2003 and it is certified by MS ISO 14001 and OHSAS 18001. To make sure there is no hydrated clinker in the cement, the OPC has passed through the 300µm sieve [8].

Fine Aggregate

In this study the used sand is river sand, the sieve analysis of the sand sample is presented in Graph-1 with fineness modulus of 2.957.



Graph-1: Sieve analysis of used River Sand

Water

Water is an essential element in the construction industry. The water is a must element needed for the preparation of mortar, mixing of concrete. The quality and quantity of water have a significant effect on the strength of brick, mortar and cement concrete in construction work and the source and type of water should be carefully selected. The water used for mixing and curing should be clean and free from injurious quantities of alkalis, acid, oils, salt, sugar, organic materials, vegetable growth and other substances that may be deleterious to bricks. In this study, the W/C ratio is 0.4 for all.

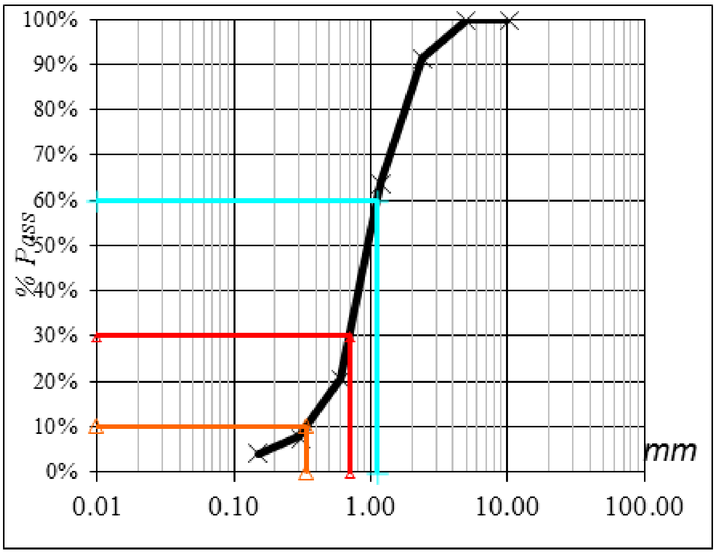
Fly Ash

Fly ash can be known as Pulverised Fuel Ash (PFA). It is a by-product from the burning of powdered coal in electric generating power plants. Fly ash is collected in the dust-collection systems (electrostatic or mechanical precipitators) that remove particles from the exhaust gases. It is one of the most common materials to be used to replace the cement in the construction field and cement industry. FA is used constantly as 20% of the weight of Cement.

Bottom Ash

The bottom ash used is from Tanjung Bin power plant and its 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 produces low calcium content. The particles of the bottom ash were larger than those particles that could be in comparable size to river sand particles. Bottom ash was ground then sieved and achieved a fineness Modulus of 3.126. BA is used in different percentage per Mixture (5%,10%,15% & 20%).

Fig-1: Grinding Bottom Ash



Graph-2: Sieve analysis of ground BA

Mix proportion and flow chart

Batching & Sample preparation

The brick mould is prepared for 35 bricks with the size standard (LWD)= (225X115X75) mm according to (JKR 2005) specifications.

Table-2: Mix design for BA in FA bricks

Qty	Cement	FA	Water	Sand	BA
Per .0776m3	Kg	Kg	Kg	Kg	Kg
Control	11.817	2.954	5.909	90.226	-
20% FA 5%CA	11.817	2.954	5.909	85.715	4.5113
20 %FA 10%CA	11.817	2.954	5.909	81.20	9.0226
20 %FA 15%CA	11.817	2.954	5.909	76.692	13.534
20%FA 20%CA	11.817	2.954	5.909	72.181	18.045

Casting & Curing

For mixing process, electric mixer machine was used to ensure all materials were mixed properly After preparing all needed raw materials and Moulds. The mould is prepared, and the mixture is poured on it after it was oiled to ease removing the mould frame and then mix were compacted manually for all mixes as in photo-2. In the second day of Mixing the mould taken off and the samples all brought a side to their perspective place to be cured. The curing for this study is air curing for all samples.

Photo-2: Oiling, casting and compacting Process

Fig-2: Air Curing of bricks

Testing

All the samples undergo their perspective testing in 7, 14 and 28 days.

Compressive Strength

The test was carried out using a Universal Testing Machine (UTM), and Calculation of compressive strength was conducted according to the following equation: = (Max Load) ⁄ A =N/mm2

Flexural Strength

Flexural strength test was conducted to determine the ability of the specimen to resist the stress, the test also using UTM and the calculation results were calculated as follows:

$$p = \text{Max Load}/(\text{Width}*\text{Depth})$$

Initial Water absorption

Moisture absorption rate used to measure the amount of water absorbed under specified condition. At first, the testing was to obtain the initial water absorption of brick; the weight of sucked water undergoes for reading in every minute followed by 5 Mins time and half hour then for one hour and lastly for 24 hrs in every seventh day. The reading is also collected for 14 and 28 days. Water absorption can be calculated from the following formula

$$\text{Absorption, \%} = 100\ (W_{(Sat)} - W_{(Dry)}) / W_{(Dry)}$$

RESULTS AND DISCUSSIONS

Compressive Strength Results

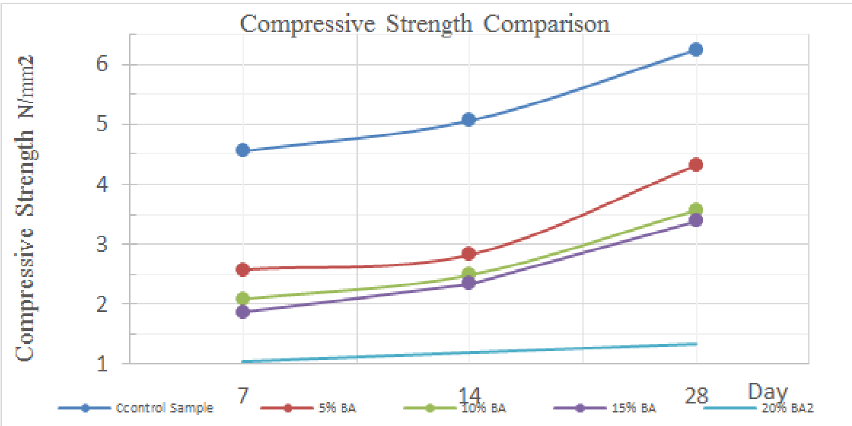


Fig-3: Variation Of Compressive Strength

The results of compressive strength of fly ash brick specimens subjected to air curing with 7, 14 and 28 days of curing period. According to the compressive test, the strength recorded its highest at 5% replacement of BA, and it is low when compare it with the control sample shows the highest result of compressive strength. The graphs of the descending values of experimental concrete mix showed a downswing at fixed w/c, with the increase in BA content as a substitute of sand in concrete. It is also indicated that the strength was affected by many factors such as the BA replacement percentage and the curing age as well as the curing method. BA is irregular, and the surface is rough and uneven as well as it is porous where of & In 2000 who stated that “the BA shows slightly more compressible as compared to the typical behaviour of sand. The trend of the compressive strength is almost similar to flexural strength and almost similar to the findings by [9].

Flexural Strength Results

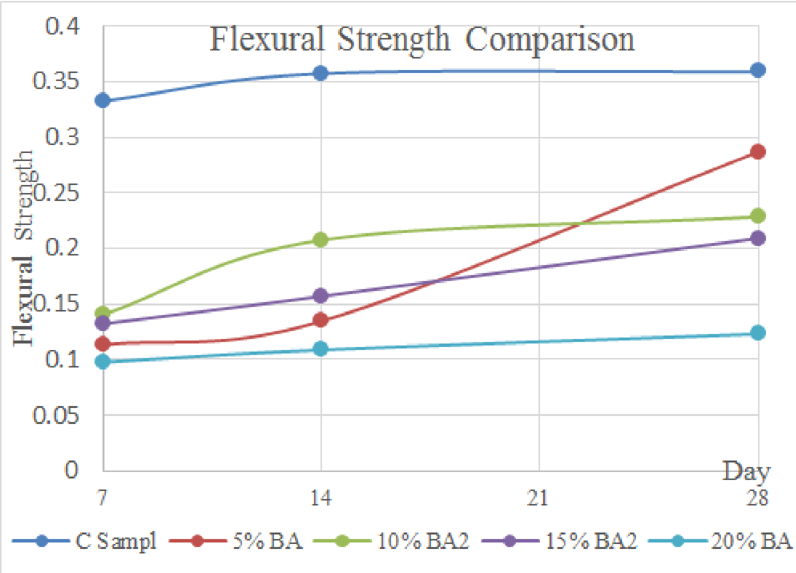


Fig-4: variation of Flexural strength

Figure-4 shows the results of Flexural strength of cement sand brick; the average reading from the flexural test results of five samples of each type of samples are taken to increase the accuracy of the reading. The result indicates that a specimen containing 5% of BA has the highest flexural strength among all replaced samples, but it is also less than the control sample. The graph illustrates a huge increment of the flexural strength for most of the tested sample rather than control, especially in 28 days. The delay in hydration and slow pozzolanic activity of FA and BA at early curing period may be the possible explanation for decrease noted in flexural strength of bottom-ash Fly ash bricks at earlier ages.

The relationship between Flexural and compressive strength

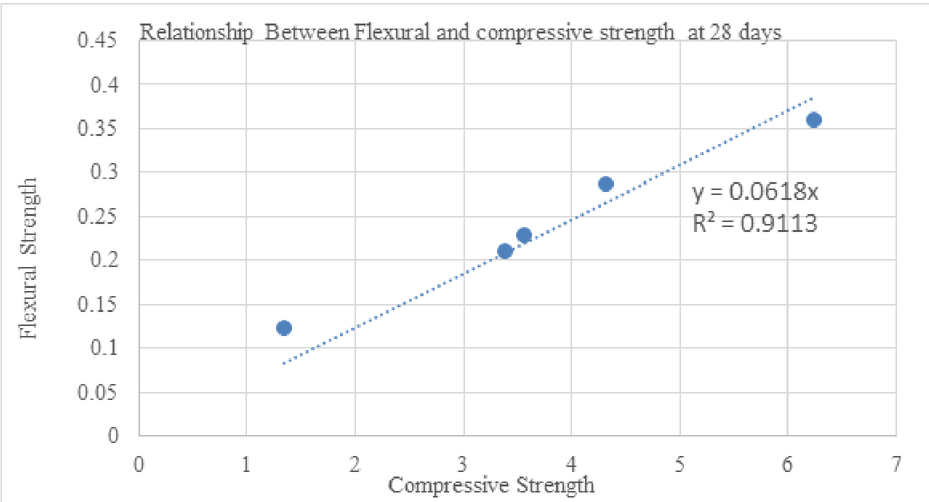


Fig-5: The relationship between Fc & Ft

By comparing the flexural strength at 28 days, the flexural strength of Bottom ah replacement in all samples with different percentages and are approximately 6-9.5% of its compressive strength, whereas it is about 5.8% in the control sample. It shows that the behaviour of CBA replacement in the sand is more than the control sample as shown down in Figure-5.

Density of the brick

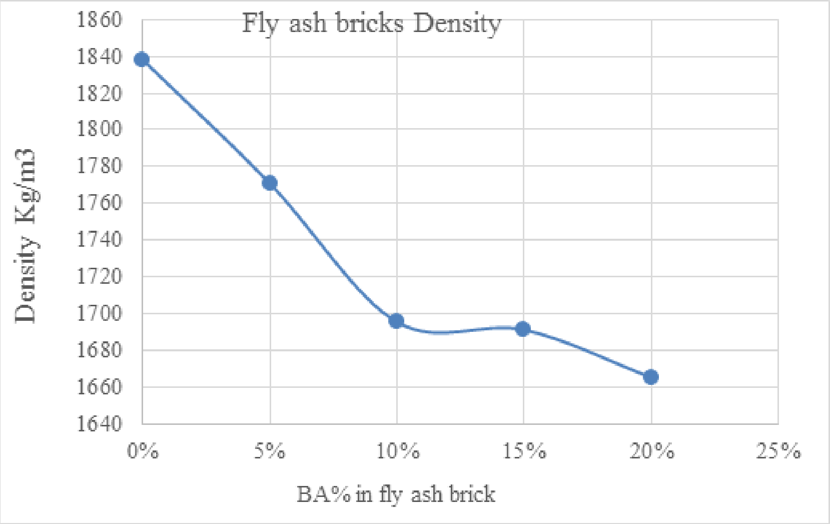


Fig-6: The relationship between Fc & Ft

The results show that control sample which has 0% of CBA was the heaviest sample and so the highest density whereas 20% of CBA showed the lowest density and that is supported by the findings that obtained by [1]. Who revealed that the air-dried density of the concrete showed a marked decline due to the low specific gravity of Coal Bottom Ash.

Water absorption Results

Water absorption test is used to test the ability of the bricks to absorb water at a specific time. The water absorption test is a vital laboratory analysis and an essential factor in determining the durability of cementitious systems. This test is only conducted on the concrete of 7,14 and 28 days. The result of the rate of water absorption of the bricks with different percentages of BA is showed in Figure-7. In general, bricks are considered as unsuitable when they have a high percentage of water absorption. From the graph, it is clear that water absorption increases when the percentage of BA increase when replacing sand. The reason of the increment of water absorption as the percentage of replacement goes higher is to the porous characteristics, irregularity, spherical shaped and complicated texture this supported by [10] CBA a porous material and absorb more water than sand.

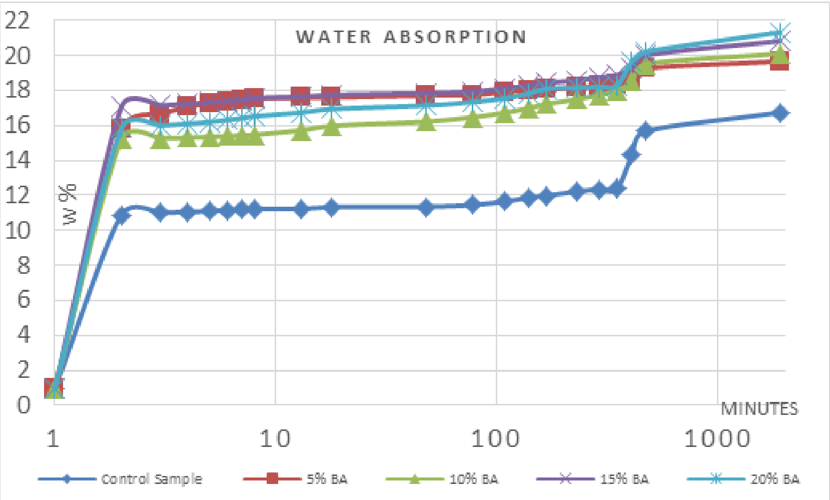


Fig-7: Variation of W% in 24 hrs

CONCLUSIONS

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 ash in construction when proper and established standards as.

- The environmental benefits will occur and lead to a decrease of CO_2 emissions by 0.9 tonnes for each ton of fly Ash used as well as reduce Natural sand usage.

- 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.
- The delay in hydration and slow pozzolanic activity of FA and BA at early curing period may be the possible explanation for decrease noted in flexural strength of fly ash-bottom ash concrete at earlier ages. Flexural strength of these mixtures got better at long-term strength on use of BA as a partial or total replacement of fine aggregate.

Several recommendations had been identified for the future development of coal bottom ash (BA) and fly ash (FA) as a replacing material in the brick industry. Hence, the following recommendations are:

- The study on the durability of cement-sand brick such as chemical attack resistance, fire resistance and thermal conductivity
- The study on the addition of superplasticizer to enhance the early strength of mortar brick.
- Bottom ash may be used as a partial replacement of natural aggregates, with finer bottom ash used as sand.

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