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Potential of Coal Bottom Ash as Fine Aggregates in The Production of Lightweight Brick

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Abstract

The use of coal bottom ash, a by-product from the coal burning process in lightweight bricks production is getting more attention worldwide including in Malaysia. The main objective of this research is to assess the extended potential of bottom ash to produce lightweight bricks. The green technology-based lightweight bricks in this study are designed using the by-product resulting from the burning of pulverized coal in thermal power plants for electric power generations. The burning of pulverized coal was questioned extensively over the last decades due to the carbon dioxide emission which is about 2.0 billion tons annually. These lightweight bricks are produced from the combination of specifically graded bottom ash, classified pozzolanic ashes, fine aggregates, Ordinary Portland Cement, and water. The lightweight bricks were subjected to a few laboratory assessments including compressive strength test, density test, and water absorption test. It was observed that the C2 brick and C3 brick at 60% and 100% addition of bottom ash, respectively had comparable compressive strength with other commercialized bricks (cement-sand brick and clay brick). The addition of coal bottom ash also produces the lowest density of the bricks which is about 1.2 kg/m^3. Comparison with other commercialized bricks available in the market in terms of compressive strength, density, and water absorption indicated that the bottom ash-based bricks are stronger and lighter. A comprehensive selection of good quality materials and the selected mix design produced an acceptable quality of bricks that can be considered as part of the actual construction materials. Thus, with the production of this light and strong brick, the volume of the coal ash waste that was dumped in the landfill will be substantially reduced and simultaneously the lighter bricks will reduce the dead loads supported by the main structures of the building.

Keywords: Bottom ash, aggregates properties, lightweight bricks production

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1. Introduction

A combustible black sedimentary rock or known as coal is one of the main and important sources of combustion to be used for electricity generation. In Malaysia, several electric power generation locations have actively used coal for combustion purposes since 1988. There are two types of ash produced from this combustion process, namely, fly ash and bottom ash. The resulting ash consists of fly ash amounting to 75% to 85% and bottom ash is between 15% to 25% (Fauzi et al., 2016). Coal bottom ash piled up in open areas can cause air and water pollution. Therefore, the best measure is to use this coal ash by making it a building material (Zainal et al., 2018).

The use of coal ash is increasingly gaining attention among researchers around the world. A study conducted by Warid et al. (2016) has successfully produced a fine material using this coal ash and this fine material hardens in a very short time and also has a high adhesive strength on the third day of the test (10 MPa). The production of building materials using coal is an excellent material especially if the work involves highway repairs etc. which saves time and so on. While Ji et al., (2019) and Dong et al., (2019) have also successfully produced this coal ash -based material and serve as a heavy metal trap found in wastewater from factories and soils.

The porous microstructure of the coal ash in the production of products such as adsorbent material successfully helps to prevent the occurrence of pollution to rivers and soils. Ghosh et al. (2019) have produced fine aggregates from this coal ash to replace sand. Apart from fine mortar, Silva (2017) has produced ceramic products using this coal ash. Thus, based on the literature review, the ashes from the combustion of coal have a high potential to be used as a building material and have the best characteristic properties.

The use of coal ash, especially fly ash, is very widespread, especially in factories for the production of composite cement and so on, however, bottom ash has not been fully applied due to several factors and restrictions. Among them are the physical and chemical properties of the ash which is less active and is still under research and development. However, based on several previous studies, the findings found that the use of bottom ash is seen to have great potential to be used as a building material, especially in the production of bricks (Suksiripattanapong et al., 2020; Zhou et al., 2020; Bonet-Martínez et al. al., 2020). The porous microstructure of this coal ash makes it a lighter material but has a high density. This is the advantage of this coal ash to be used as a building material such as lightweight bricks and other construction materials (Sajjad et al., 2019).

The lightweight brick in this study is a product produced from bottom ash using an optimal mix design. This lightweight brick is manufactured to meet the specifications in Malaysian Standard MS 7.6: 1972 and British Standard BS 3921: 1985. It also has the potential to be designed at varying strengths according to suitability and user requirements such as the production of normal bricks (strength between 1 MPa up to 5 MPa), exposed bricks (strength from 5 MPa up to 10 MPa), and engineering bricks (more than 10 MPa). Therefore, this lightweight brick has its special value and is more durable.

The composition of this lightweight brick is a mixture of several materials such as coal ash that has gone through a grading process, pozzolanic material, fine mortar, Portland Ordinary Cement, and water. Proper mix design will ensure the production of quality products and produce strength at the most optimal level. Therefore, this study is very important to ensure the correct bottom ash content and then make a comparison with some types of bricks available in the market. This study was carried out to look at the potential of coal bottom ash to be used as fine aggregate replacement materials in the production of lightweight brick.

2. Methods

In order to determine the properties and performance of Lightweight brick containing coal bottom ash, three (3) mixes samples were produced named B1, B2, and B3. B1 is a control sample containing OPC: Sand at a mix proportion ratio of 1:1. B2 contains 1:0.4:0.6 of OPC:Sand: Bottom Ash while B3 contains 1:1 of OPC: Bottom Ash. Details mixes proportions of all prepared samples are as shown in Table 1.

Table 1. Mixture design for the production of coal ash-based bricks

Samples	Ordinary Portland Cement (%)	Sand (%)	Bottom ash (%)	Water (%)
B1	100	100	0	100
B2	100	40	60	100
B3	100	0	100	100

To produce the samples, Ordinary Portland cement Type 1: 32.5R was used as a binder and natural river sand was used as fine aggregates, coal bottom ash (CBA) was used as fine aggregate replacement material at 60 and 100% replacement by weight CBA was collected from Sultan Abdul Aziz Shah Klang Malaysia power plant. CBA was then crushed in the crusher machine and sieve to a size passing 10mm and retained at 600µm sieve before it is used as fine aggregate replacement materials. The water to cement ratio at 0.4 was used as a hydration activator and workability substance in the preparation of samples. The properties of cement, sand and bottom ash used in this study are as shown in Table 2 and Table 3.

Table 2. Chemical composition of Ordinary Portland Cement and Bottom Ash

Chemical constituent	Ordinary Portland Cement (%)	Bottom Ash (%)
SiO_2	22.01	68.04
Al_2O_3	5.62	25.01
Fe_2O_3	0.55	2.20
TiO	-	1.47
CaO	65.03	1.72
MgO	0.80	0.02
SO_3	1.55	-
LOI	2.05	1.69

Table 3. Natural river sand and bottom ash properties

Properties	ASTM	Natural river sand	Coal Bottom Ash
Water absorption (%)	ASTM C1585-13	1.05	14.10
Specific Gravity	ASTM C127-12	2.73	1.82
Colour	ASTM C979-16	Light	Dark black
Surface texture	ASTM C1252-17	Glassy	Porous
Shape	ASTM D3398-00	Almost rounded	irregular
Fineness modulus (%)	ASTM C33-03	3.8	2.6

3. Results and Discussion

Figure 1 presents the compressive strength of brick produced. From the data obtained the compressive strength of B1, B2 and B3 are 33.5N/mm^2, 21.6 N/mm^2, and 16.3 N/mm^2 respectively. Bricks B1 is having a higher strength as compared to B2 and B3. The lowest strength of B3 present that brick with 100% Bottom ash explained that the utilization of Bottom Ash will reduce the compressive strength of brick. The reduction strength percentage from the strength of cement sand brick to bottom ash cement sand brick is around 50%.

The data obtained also show that as the higher Bottom ash used in the production of brick the lower the strength will be produced. This might be due to the lower strength of Bottom Ash that contains porous structure Bonnet et al (2020) stated that the porosity structure of basic materials used is responsible for producing lower strength

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of product produced. The irregular shape of Bottom ash also may respond to form more void areas in the brick matrix. Suksiripattanapong et al. (2020) have a finding that is tailored with the statement on the effect of the irregular shape of aggregates used has played an important role in providing high compressive strength of concrete. The irregular shape of bottom ash used in this study was also identified as presented in Table 3.

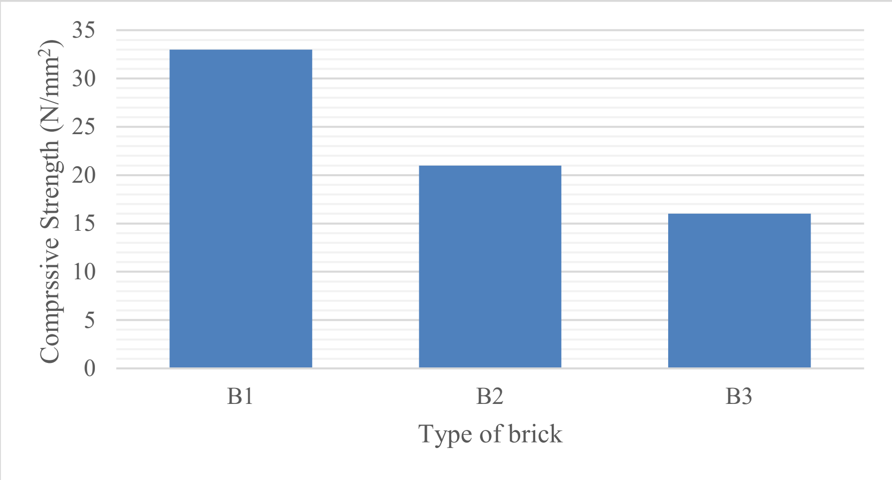

Figure 1. Compressive strength of lightweight bricks

Figure 2 presents the density of brick samples prepared. From the figure, it is shown that the density of cement sand brick (B1) is 2180kg/m^3 while the density of brick containing 50%sand and 50% Bottom Ash (B2) is 1500 kg/m^3. The density of B3 which contains 100% BA was identified as having a density of 1050 kg/m^3. The density of B2 and B3 was found to be lower than B1 about 31% and 51.8% respectively. The low density of brick containing bottom ash was influenced by the lower density properties of bottom ash as compared to river sand as shown in Table 3. The specific gravity of Bottom Ash was found 33% lower than natural river sand used. The lower density of bottom ash has successfully produced lightweight properties to Bottom Ash Brick and made those bricks produced lighter as compared to bricks using river sand. The porous microstructure condition of the bottom ash is a major contributor to the production of lighter bricks. This is also due to the density of the coal bottom ash material itself which has a lower density than sand i.e., less than 1.8 g/cm^3 (Temuujin et al., 2010).

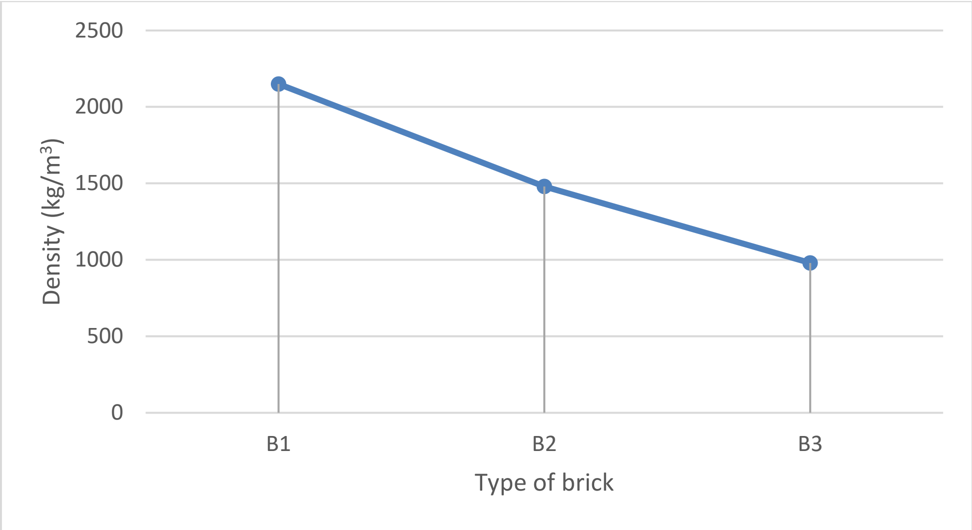

Figure 2. Density of bricks

Figure 3 presents the relationship of density to the compressive strength of brick produced and tested for this investigation. From the relationship, it can be seen that linear regression was developed with the R2 value of 0.9778. The significant relationship explained that the higher the density of brick will produce higher compressive strength of brick. The relationship pattern was agreed by many researchers as their findings also presented the same pattern n (Fauzi et al (2016), Ghosh et al (2019), Sajjad et al (2019), Suksiripattanapong et al. (2020). The relationship of properties in explaining the effect of density on the compressive strength of brick was expressed to an equation:

$$Y = 66.44x - 13.62 \qquad (1)$$

Where:

Y = density of brick (kg/m^3)
X = compressive strength of brick (N/mm^3)

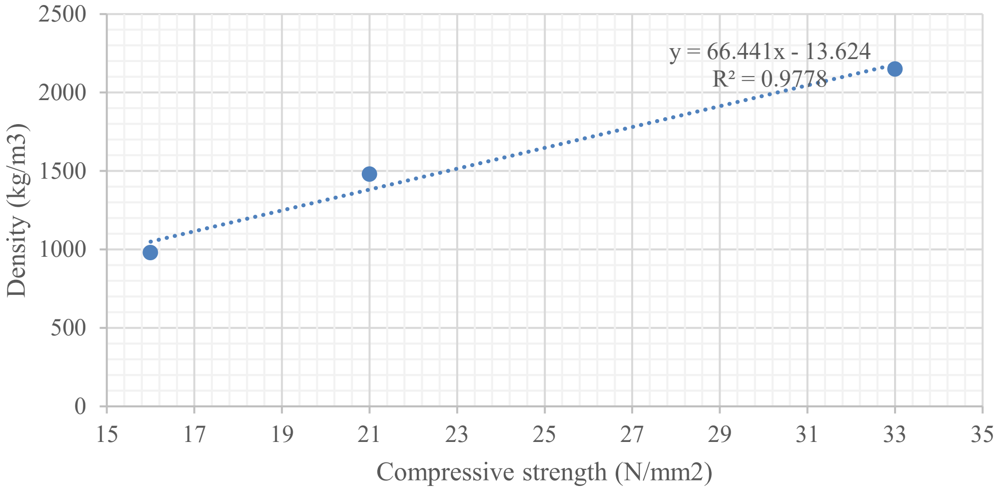

Figure 3. Density vs compressive strength

Figure 4 presents the water absorption of each type of brick produced in this investigation. The water absorption of B1, B2, and B3 is 7.8%, 9.65%, and 16% respectively. From the figure, it is portrayed that brick produced from river sand (B1) is having a lower water absorption value as compared to brick B2 and B3. The figure is also presented that brick containing 100% Bottom ash as fine aggregate (B3) is having a water absorption value of more than 100% as compared to brick produced from river sand (B1). As the mix of sand 50% with bottom ash, 50% used as fine aggregate in the production of brick shows the water absorption level is 23.7% higher than a brick produced from Natural River sand.

Figure 5 presents the relationship of water absorption versus the density of brick. From the graph, the relationship of water absorption to the density of brick produced is linearly opposite relationship. A significant water absorption value drops as the density of brick increases is portraits. The relationship also explained that the water absorption of brick is higher when the Bottom Ash was used as fine aggregate in replacing natural river sand. Even though the water absorption of bottom ash brick is high it is still satisfied the standard requirement BSEN 771-1 which is 17%.

The high value of water absorption by bottom ash brick as compared to normal sand brick might be due to the high water absorption properties of bottom ash as presented in Table 3.0 where the absorption level of bottom ash is 14.10% as compared to natural river sand which is only 1.15%. This finding was also satisfied by Zainal et al (2018), Zhou et al (2020), and Warid et al (2016).

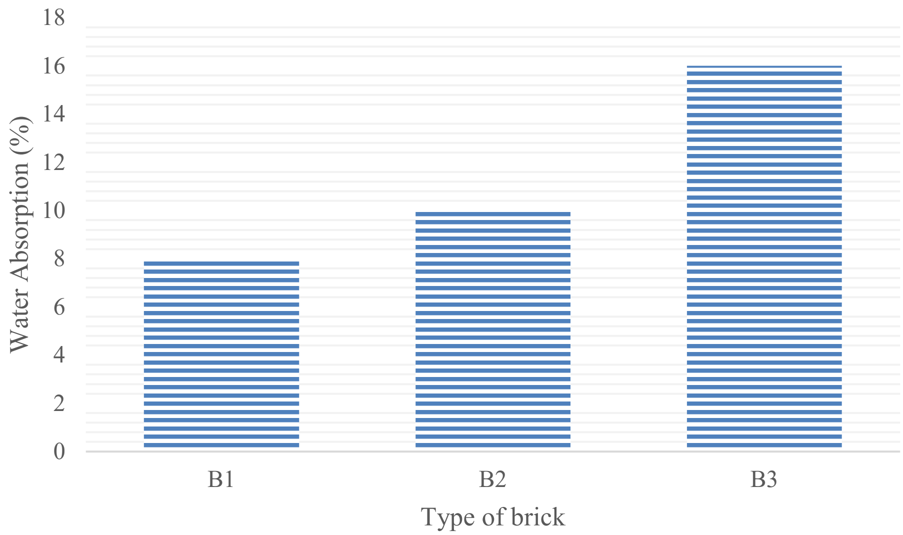

Figure 4. Water Absorption of brick

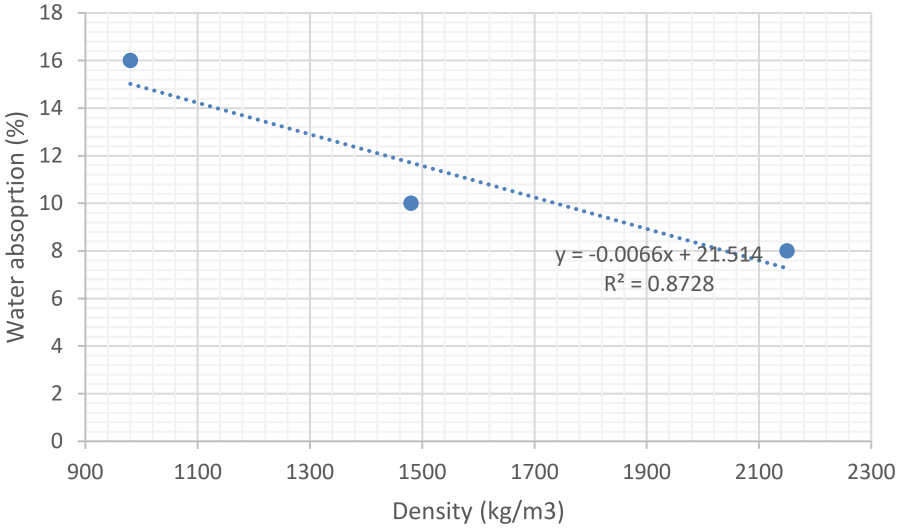

Figure 5. Density vs water absorption

4. Conclusions

From all the data obtained from this research, it is concluded that:

1. The coal bottom ash has a different property as compared to natural river sand
2. The inclusion of coal bottom ash successfully reduces the density of a brick
3. The utilization of coal bottom ash as fine aggregates replacement materials has reduced the compressive strength of brick
4. The water absorption of brick was also found to be increased as the content of coal bottom ash increased
5. The potential of using coal bottom ash as fine aggregate replacement materials to natural river sand is proven especially in producing lightweight brick.

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