Progress in Engineering Application and Technology Vol. 3 No. 2 (2022) 183–191
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PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Use of Palm Oil Boiler Bottom Ash as Replacement Materials in Concrete Mix

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DOI: https://doi.org/10.30880/peat.2022.03.02.018
Received 27 January 2022; Accepted 07 November 2022; Available online 10 December 2022

Abstract: Lightweight concrete is widely implemented in the construction industry to replace conventional concrete due to the high self-weight. Furthermore, the waste that produced from palm oil industry could be used as the material in concrete mixture to partially replace with the fine aggregate to solve the problem of resource depletion. The used of palm oil boiler bottom ash is the suitable fine aggregate replacement material to produced lightweight aggregate concrete. The objective of this research is to study on the performance of the lightweight concrete that using the bottom ash in the concrete mix compared to the conventional concrete. This research also important to identify the optimum percentage of palm oil boiler bottom ash that was replaced in the concrete. The samples sized with 100 mm x 100 mm x 100 mm with the percentage of fine aggregate replacement are 10.00 %, 20.00 % and 30.00 %. The characteristic strength of concrete cube that were used in this research is 25 N/mm^2. The mechanical properties testing methods that carried out in this research were slump test, water absorption test and compression test. At the end of the research, the optimum percentage of palm oil boiler bottom ash that was replaced in the concrete mixture is 20.00 %. The average compression strength for this replacement percentage was 39.24 MPa. The concrete cube samples that contain 20.00 % palm oil boiler bottom ash replacement had highest compression strength compared to other concrete cube samples with different replacement percentage.

Keywords: Bottom Ash, Palm Oil Boiler Bottom Ash, Replace Fine Aggregate

1. Introduction

The construction industry is one of the most important industries that play an important role in the development of a country. Over the ages, more buildings and infrastructures are constructed in Malaysia to meet the demand of the increasing population. Concrete is the most commonly used construction material in this industry. This construction material contains high self-weight and caused the lightweight concrete is more widely implemented in construction industry.

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Lightweight concrete is a mixture made with a lightweight coarse aggregate such as shale, clay, or slate which giving additional qualities and lessened the dead weight. It is lighter than conventional concrete because the lightweight aggregate used will develop a porous structure in it. It is more flexible and easily transportable compared to conventional concrete. In addition, it only required little support from materials such as steel and additional concrete. This makes it cost-effective during the design and building stage, especially for a larger building project. There are three types of lightweight concrete which is lightweight aggregate concrete, aerated concrete, and no fines concrete. The lightweight concrete that used in this research is lightweight aggregate concrete.

Palm oil industry grows tremendously in Malaysia and generated more waste during their production activity. There is an abundance of raw materials available of the palm tree consisting of around 90.00 % of biomass wastes and only around 10.00 % of oil. About 90 million tonnes of oil palm fruit production was recorded in 1998; however, 43.00-45.00 % of this was mill residues in the form of empty fruit bunches (EFB), shells, and fibre (Muthusamy et al., 2018). This waste is usually being dumped or disposed of by the factory as landfills. If the waste is not deal with properly, it will be causing the environmental issue due to this human activity. Concerning these issues, palm oil boiler bottom ash is proposed to replace the fine aggregate in concrete.

In Malaysia, the main sources of fine aggregate are from the river. Based on the report by the Department of Minerals and Geosciences of Malaysia, the sand mining activities in Malaysia have been trending in increasing mood which made a difference from 37.3 million tonnes in 2011 to 46.7 million tonnes in 2016 (Muthusamy et al., 2018). Excessive removal of fine aggregate from the river may significantly tear the natural equilibrium of the aquatic habitats apart. When the removal of fine aggregates occurs at the active riverbed, it will disrupted the sediment mass balance in the river downstream and inducing channel adjustments extending considerable distances beyond the extracted site itself (Teo et al., 2017). After the long-term, the riverbank will destabilise and the riverbed will become shallow due to the soil erosion. Thus, flash flood will easily happen during rainy season. Therefore, in this research, we proposed replacing the fine aggregate in the concrete with palm oil boiler bottom ash to decrease the usage of river sand.

1.1 Objectives and Scope

There are three objectives of this research. The first objective is to investigate mechanical properties of palm oil boiler bottom ash. The second objective is to determine the optimum percentage of palm oil boiler bottom ash that was replaced in the concrete. The third objective is to investigate the suitability of oil palm boiler bottom ash as a material in lightweight concrete. This research focuses on using Palm Oil Boiler Bottom Ash to replace fine aggregate in the concrete mixture. Then, the Palm Oil Boiler Bottom Ash material was mixed with natural coarse aggregate and Ordinary Portland Cement. The grade for the concrete mixture was Grade 25 and calculate by using DOE method. Palm Oil Boiler Bottom Ash material will undergo sieve analysis test before the mixing process with the coarse aggregate and cement. The percentage of Palm Oil Boiler Bottom Ash replacement are 0.00 %, 10.00 %, 20.00 % and 30.00 % was refer to the research that done by (Saputra et al., 2017) and (Roslan et al., 2020) with the cube samples with size 100 mm x 100 mm x 100 mm. There is total 48 concrete cubes in this research and they were tested at 7 days and 28 days curing period. The test that carried out in the laboratory is slump test, water absorption test and compression test.

2. Materials and Methods

During the materials preparation phase, the palm oil boiler bottom ash will be sieved by using 5mm sieve to ensure that it is suitable for the replacement of fine aggregate in concrete mix. The first objective of this research was to identify the mechanical properties of palm oil boiler bottom ash aggregates and this objective was achieved through slump test, water absorption test and compression strength test. The optimum content for replacement of fine aggregates with palm oil boiler bottom ash aggregates in concrete mixture was also identified from the result of the laboratory test. From the result from this research, the suitability of palm oil boiler bottom ash as the replacement materials in lightweight concrete will be determined.

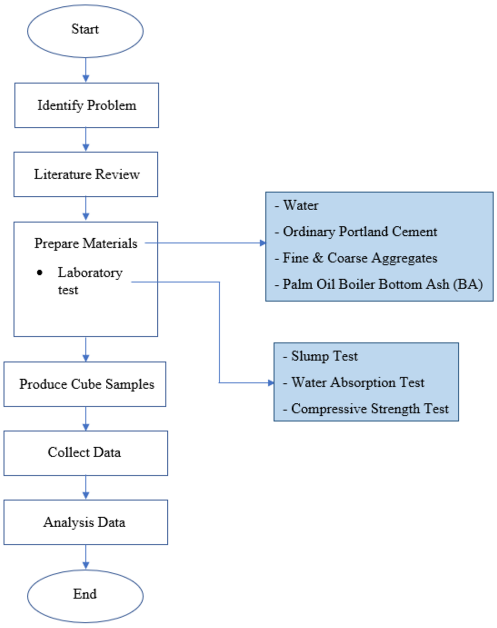

Figure 1: Flow chart of methodology

2.1 Materials

In this study, the main materials of the concrete were cement, coarse aggregates, fine aggregates, Palm Oil Boiler Bottom Ash, and water. Palm oil bottom ash is used as the replacement materials for the fine aggregates in the concrete mix according to the proportion set. Therefore, the dimension of the concrete specimen was a cube shape which has 100mm on each side. The selection of these materials was standardized to avoid any inconsistent data obtained for each specimen.

2.1.1 Palm Oil Boiler Bottom Ash

Palm oil boiler bottom ash that is used in this research was obtained from Kilang Sawit Keratung 3, Bandar Tun Razak, 26900 Pahang. The bottom ash was delivered straight away from the factory site to the research laboratory in UTHM campus Pagoh. The material was treated similarly to the fine aggregate in this research such as undergoes a sieve analysis test before the mixing process because it will be used as the replacement for the fine aggregate. The material also will be cleaned and washed with tap water to remove the excess organic substance and chemicals on it. After that, it will be dried in the open space and stored until the casting process.

Figure 2: Palm oil boiler bottom ash

2.2 Methodology

2.2.1 Preparation of Materials

In this research, the dimension of the sample cube used is 100 mm x 100 mm x 100 mm. A total of 12 of the palm oil boiler bottom ash concrete cubes will be used for each testing. The total volume per trial mix in this research is 0.012 m^3. The quantity of the material used such as cement, water, fine aggregate, and coarse aggregate in the Concrete Mix Design (DOE Method) is shown in Table 1. In addition, the total weight of palm oil bottom ash used as the fine aggregate replacement with the different percentages in concrete mixture per trial mix is listed in Table 2.

Table 1: The quantity of the material used in the concrete mix design (DOE method)

Quantities	Cement (kg)	Water (kg or L)	Fine aggregate (kg)	Coarse aggregate (kg)		
				10mm	20mm	40mm
Per m^3 (to nearest 5kg)	360	180	1009.25	-	825.75	-
Per trial mix of 0.012 m^3	4.32	2.16	12.11	-	9.91	-

Table 2: Total weight of palm oil boiler bottom ash used as the fine aggregate replacement per trial mix of 0.012 m^3

Percentage of Palm Oil Boiler Bottom Ash (%)	Total weight of Palm Oil Bottom Ash (kg)	Total weight of fine aggregate (kg)
0	0	12.11
10	1.21	10.90
20	2.42	9.69
30	3.63	8.48

The sample with 0.00 % replacement of the palm oil boiler bottom ash is used as the control for this research. The mechanical properties of the control sample are compared with the other concrete cube samples which contain different replacement percentages of the palm oil boiler bottom ash in the concrete mix. All the concrete cube samples are left in the water tank for 7 days and 28 days curing period before the laboratory testing is carried out.

2.2.2 Calculation Amount of Concrete Cube

Based on Table 3 and Table 4, the total amount of the concrete cube samples that used in this research is 48 cubes. Thus, cube test for 7 days and 28 days, there are 12 concrete cubes is used in compression test and 12 concrete cubes are used in water absorption and hardened density test for each curing period.

Table 3: Cube test for 7 days and 28 days

Test	0	10	20	30	Total cube
Compression test	6	6	6	6	24
Water absorption and hardened density	6	6	6	6	24
					48

2.3 Laboratory Test

2.3.1 Slump Test

A slump test is a laboratory test that will be carried out by following BS EN 12350-2:2009 (*Testing Fresh Concrete Part 2: Slump Test*). This test is usually carried out in the laboratory to measure the workability of the concrete. Three layers of concrete are placed separately into the steel cone. Each layer of concrete is tapped 25 times by using a tamper to ensure uniform compaction of the concrete in the cone. The third layer is the finishes layer thus the excess concrete will be cut off to produce a smooth plane surface on the top of the cone. After that, the cone is lifted and the slump is measured and recorded.

2.3.2 Water Absorption Test

Water absorption test is carried out based on BS 1881: Part 122: 1983 (*Testing Concrete: Method for Determination of Water Absorption*). The sample will be cleaned to remove the fine particles and dust on the surface of the sample. The initial mass of the dry concrete sample will be recorded. Then, the distilled water will be prepared to submerge the sample for 30 minutes. After 30 minutes, the sample is taken out and the surface water is dried. The mass of the wet concrete sample is measured and recorded. The percentage of water absorption is calculated by using the formula below.

$$W.A. = \frac{W_{sat} - W_{dry}}{W_{dry}} x\ 100\%$$

2.3.3 Compression Strength Test

The compression strength test is carried out in the laboratory based on BS EN 12350-2: 2009 (*Testing Hardened Concrete Part 3: Compressive Strength of Test Specimen*) by using the concrete compression machine. The compression test is used to determine the compressive strength of the concrete. This test was also used to determine the rate of strength gained at different periods of curing time. In short, the compressive strength of concrete is affected by the grade and quality of the concrete. The higher the grade of the concrete, the higher the compressive strength of the concrete. Therefore, 7 days and 24 days of concrete cube shape samples are used in this test.

3. Results and Discussion

3.1 Slump Test

Table 5: Result of slump test

Percentage of Bottom Ash (BA) (%)	Slump Value (mm)	Type of Collapse	Degree of Workability
0	47	True Slump	Medium
10	40	True Slump	Medium

20	36	True Slump	Medium
30	31	True Slump	Low

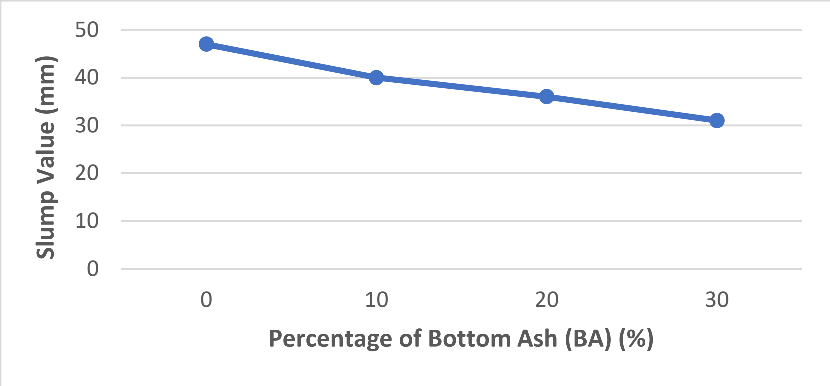

Figure 3: Graph of slump value against percentage of bottom ash

Based on result recorded in Table 5, the slump value recorded for the normal concrete mixture was the highest which was 47 mm. While for the slump for 10.00 %, 20.00 % and 30.00 % of bottom ash, the slump value decreased to 40 mm, 36 mm and 31 mm respectively. This is because the Bottom Ash that added into the concrete mixture will absorb the water content in the concrete mixture and cause the workability of the concrete mixture to decrease. Hence, the higher the percentage of BA aggregate replaced fine aggregate in the concrete mixture, the lower the workability of fresh concrete. As a conclusion, all slump value that obtained in this test were acceptable because it was still met the requirement in the concrete mix design which is 30 mm to 60 mm.

3.2 Water Absorption Test

Table 6: Result of water absorption test with different percentage of bottom ash aggregate at age of 28 days

Percentage of Bottom Ash (BA) (%)	Average (%)
0	2.61
10	2.99
20	1.88
30	1.36

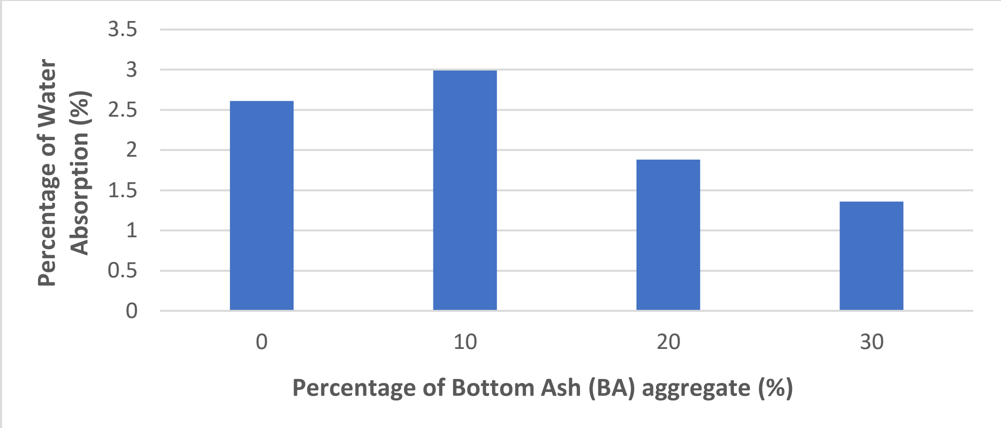

Figure 4: Graph of percentage of water absorption against percentage of bottom ash (BA) at age 28 days

Based on the result, the highest rate of water absorption was at 10.00 % of BA aggregate in concrete mixture which was 2.99 %. It is higher than the control sample at age of 28 days. However, the average water absorption of the concrete mixture with 20.00 % and 30% of BA aggregate decreased gradually which was 1.88 % and 1.36 %. When the percentage of BA aggregate in the concrete mixture increased, the C-S-H gel formation reduced the pore size in the concrete mixture. This caused the water absorption of the concrete to decrease gradually. In summary, the percentage of BA aggregate in the concrete increased, the percentage of water absorption decreased.

3.3 Compressive Strength Test

Table 7: Result of compressive strength test with different percentage of BA at age of 7 and 28 days

Percentage of Bottom Ash (BA) (%)	Average Strength of Concrete Cube Samples (MPa)	
	7 Days	28 Days
0	17.14	27.44
10	19.78	27.95
20	27.02	39.24
30	26.84	28.69

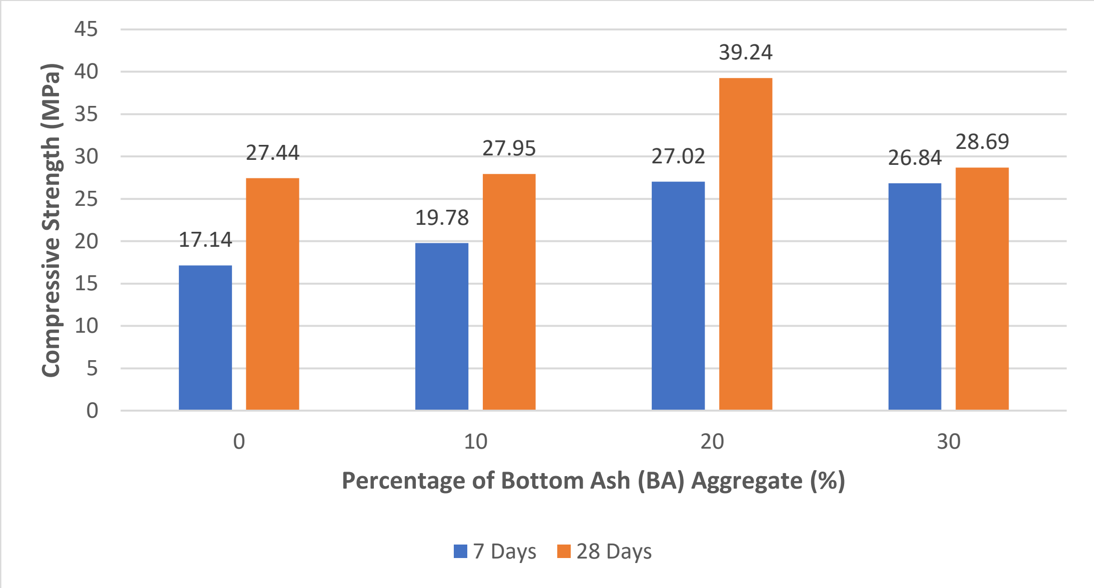

Figure 5: Graph of compressive strength against percentage of bottom ash (BA) aggregate at age 7 and 28 days

The characteristic strength of concrete cube that were used in this research is 25 N/mm^2. Based on the observation from Table 7, the concrete cubes that containing the 0.00 % and 10.00 % of BA at age of 7 days do not achieve the grade of design concrete mix. The cube samples that started achieving the grade of concrete design mix at age of 7 days were the concrete that contain 20.00 % and 30.00 % of BA. The minimum average compressive strength for the concrete cube samples at the age of 7 days is the concrete cube samples with 0.00 % of BA which is 17.14 MPa. Thus, the compressive strength of the concrete cube samples with the minimum percentage of BA replacement was higher than the control samples which is 19.78 MPa. For the concrete cube samples with 20.00 % of the BA, the compressive strength at the age of 7 days is slightly higher than the compressive strength of 30.00 % BA concrete cubes which is 27.02 MPa and 26.84 MPa respectively. Both of these concrete cubes met the grade of design concrete mix at 7 days.

At the age of 28 days, all concrete cube samples have achieved the grade of concrete design mix. The compressive strength of the concrete cube samples was slightly lower than the compressive strength of the concrete cube samples with 10.00 % of BA replacement at the age of 28 days which is 27.44 MPa and 27.95 MPa respectively. The concrete cube samples with 10.00 % of bottom ash replacement had the highest water absorption while had the low compression strength. This is because this concrete cube samples contain higher porosity compared to other concrete cube samples. Thus, it can absorb more water while had low compression strength. The concrete cube samples with 20.00 % of the BA replacement achieved the maximum compressive strength among all the concrete cube samples in 7 days and 28 days. Based on Figure 5, it shown that the compressive strength of the concrete cube samples increased when the curing age of the concrete cube samples increased. Furthermore, when the percentage of BA increased, the compressive strength of the concrete cube samples decreased. In summary, the optimum percentage of the BA replacement with the fine aggregate is 20.00 %.

4. Conclusion

After the accomplishment of the laboratory testing, the objective that mentioned at above was achieved. The tests that were conducted along this research were slump test, water absorption test and compressive test. The first objective of this research was to identify the mechanical properties of Bottom Ash (BA) aggregates and this objective was achieved through slump test, water absorption test and compression strength test. The optimum content for replacement of fine aggregates with Bottom Ash (BA) aggregates in concrete mixture was also identified which is 20.00 % of bottom ash replacement in concrete mixture. Therefore, from the result from this research, it may be deduced that palm oil boiler bottom ash was suitable as the replacement materials in lightweight concrete.

Acknowledgement

The authors would like to express gratitude and thank Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

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