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Alkaline Activated Coal Bottom Ash as Partial Cement in Mortar

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Abstract: In Malaysia, despite the carbon reduction plans, carbon dioxide (CO_2) emissions and the associated rick of climate change are a cause of major concern. CO2 emissions due to cement manufacturing is pressing issue as well. In addition, there is a raising concern due to excessive of Coal Bottom Ash (CBA) from coal plants. The aim of this study is to examine the properties of different percentages of CBA as partial cement in mortar. To enhance the properties of alkaline activated CBA, a suitable mixture or percentage of CBA which were 0%, 20%, 40% and 60% with 0%, 2%, 4% and 6% of $CaCl_2$ respectively were determined. To investigate the physical properties of the CBA, specific gravity test was conducted according to ASTM D792 and particle size analysis (PSA) was done according to ASTM D422-63. The performance of the mortar was being assessed via hardened properties testing such as compressive strength according to ASTM C496 with 36 samples of cubes and split tensile strength test according to ASTM C39 with 24 samples of cylinders were being conducted. It is hypothesized that the mixture of alkaline activated CBA in mortar improved its performance. The compressive strength of 40% of alkaline activated CBA was higher than the other mixture while the controlled samples still get the highest strength compared to the other mixtures and the split tensile strength of 40% of alkaline activated CBA increased compared to the other mixtures which shows decreased at the age of 7 and 28 days. The optimum mixtures of alkaline activated CBA were 40% and it proved that the mixtures could improve the strength of mixtures. Well designed and tested mortar mixture were contributed towards the strength aspects of this prospective green construction material. In conclusion, the research was starting the fundamental overview to design eco-friendly construction material and seek purpose to reduce pollution, decrease the landfill waste and help protect the natural resources.

Keywords: Coal Bottom Ash, Calcium Chloride, Compressive Strength Test, Split Tensile Strength Test

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1. Introduction

Coal bottom ash (CBA) is a waste by-product and non-combustible material that is produced by the combustion of coal in a power plant's furnace. It is well-known in the electrical power sector as a waste by-product and non-combustible substance [1]. The process of turning wasted materials into new ones is a common occurrence. In addition, as a result of more rigorous environmental requirements, Malaysia is currently developing unique sustainable concrete building materials for the construction industry. Bottom ash, fly ash, and garbage from coal-fired power stations are additional common sources of pollution. In order to minimize waste, it has a higher impact on the overall amount produced. Researchers have invented building materials that are both durable and lightweight, as well as capable of producing electrical power [2].

The porous particle structure of CBA is advantageous for minimizing concrete's drying shrinkage [3]. CBA's influence on the workability, bleeding, setting times, compressive strength, split tensile strength, flexural strength, shrinkage and durability of concrete [4]. The clinker or cement factor has a direct effect on carbon dioxide emissions, in other words, the lower the clinker or cement ratio, the lower the carbon dioxide emissions [5]. In conclusion, ground CBA is one of the most promising ways to material substitution for carbon dioxide emission reduction. Additionally, using ground CBA as a Portland cement substitute contributes to more sustainable cement manufacturing by reducing energy and raw material use.

There has been an increased demand for coal in this nation, which has resulted in an increase in the amount of CBA produced by power plants. The Malaysian coal industry generates around 1.7 million tons of CBA per year, which is disposed of as waste and creates environmental concerns [6]. CBA slurry that is dumped into a pond might pose a number of environmental hazards. CBA production is predicted to increase because of greater energy usage, which will lead to more ponds needing to be dedicated to waste disposal, increasing the danger of pollution, according to [7]. Research on the use of CBA in concrete, which is frequently used in building, was sparked by concerns about environmental sustainability.

The aim of this research is to investigate the physical properties of CBA and mechanical properties of mortar consisting of alkali activated CBA and determine the optimum percentage of alkali activated in mortar. The physical properties are examining for this CBA properties which are specific gravity or density of the materials according to ASTM D792. The information collected for mechanical properties are the strength and potential of the mortar before produce as the material construction. For example, compressive strength test as in ASTM C39 and split tensile strength test as in ASTM C496. This result will contribute towards the durability aspects of this prospective green construction material. The material would be subjected to mechanical grinding method to produces micro ash. The CBA are sieve into several size classes to identify the particle size distribution. Sieve analysis is according to the standard BS 410-1: 2000 to obtain the CBA size. Ordinary Portland cement and natural river sand from single source being used. Calcium chloride $CaCl_2$ was chosen as the alkaline activator for the CBA as partial cement in mortar which are 0%, 2%, 4% and 6% of $CaCl_2$ were used. 0%, 20%, 40% and 60% of alkaline activated CBA are used as partial cement in mortar.

2. Assessment of Mortar Structure

The mix percentage, chemical proportion, and water-binder ratio of cement mortars all have a major impact on the split tensile strength of the finished product. Pozzolanic materials, such as micro- and nano-silica, are attracting substantial attention as a result of their improved performance when compared to other additives in the industry. The size of the particles is significant for boosting the mechanical strength of the cementitious material by increasing the size of the pores in the cementitious material. These elements have a significant impact on the strength of mortar. It is believed that this reaction enhances the hydration process and the formation of thick C-S-H gel, which ultimately results in an increase in the split tensile strength of the mortar [8]. When comparing the conventional mix value to the optimal replacement strength value, the value of the mix improves in terms of strength and durability. A further rise in the $CaCl_2$ concentration will result in a reduction in the strength of the solution [9]. According to [10], the higher the percentages of CBA in the concrete as sand replacement, the higher strength of the tensile strength can achieved. The longer the curing days, the higher the strength of the tensile strength of the concrete can achieved.

The compressive strength test results of control mixtures and geopolymer samples at 7 and 28 days. In practical application, low strength at early ages can be overcome using a small quantity of additives. Also, curing at elevated temperature is also beneficial to overcome this problem. It was observed that the compressive strengths of the 4 and 8 M samples were relatively higher than the 12M sample because of the formation of shrinkage cracks in higher molarity. It was found that the measurement of strength and shrinkage both depended on the type of $Na^{+}$and K^{+} ion present in the activator [11]. When activated bottom ash is used as a cement admixture, the effects produced on mechanical strength were dependent on the type of chemical activator added. An increase in the activator dosage at any of the examined curing durations was found to have only a minimal influence on mechanical strength based on statistical analysis of UCS values, suggesting the amount of bottom ash in the hardened materials is the most important element impacting their mechanical characteristics [12].

2. Materials and Methods

2.1 Materials

i. CBA is used as 20%, 40% and 60% of partial cement in mortar. This CBA is supplied from Manjung, Perak. The collected original CBA dried in an oven at temperature of 110±5℃ for 2 hours. Then, the CBA was placed in the Los Angeles (LA) machine for 2-3 hours. After that, for more grinding in a ball mill grinder for 15 hours to produce particles of CBA that passed 75 µm. sieve. The longer the time to grind the CBA, the fineness the size of particle of the CBA were produced. Figure 1 shows the sample of CBA after grinding for 15 hours. Figure 1 shows the coal bottom ash after grinding process.

Figure 1: Coal Bottom Ash

ii. Alkaline activator used in CBA are $CaCl_2$. Cementitious mixtures were prepared by blending of different mixtures of activated CBA and Ordinary Portland Cement (OPC) at a water/total solids weight ratio of 0.5. The investigated CBA/(CBA + OPC) ratios was 0, 20, 40 and 60wt%, while the chemical activator additions expressed as (activator/CBA ratio) which is 0, 2, 4 and 6wt% [12].

2.2 Mix design

Table 1 shows the mix proportion of mortar. Mortar mix is as follows. Type of cement used is Ordinary Portland Cement (OPC) at a water/total solids weight ratio of 0.50. Fine aggregate which is sand were used. Water cement ratio used was 0.50. Coal Bottom Ash (CBA) with different percentage to replace the cement (0-60%). (0-6%) of alkaline activator used according to the percentage of CBA mix.

Table 1: Mix Proportion of CBA and $CaCl_2$

Percentages (%)	CBA (%)	$CaCl_2$ (%)	Cement (%)
0	0	0	100
20	20	2	80
40	40	4	60
60	60	6	40

2.3 Specimens and tests

The size of cubes 50mm × 50mm × 50mm cubes were prepared for 36 samples for compressive strength test. The preparation of cube mold must be prepared before started the mixing process. Furthermore, make sure there is no hard dirt on the flanged face preventing the parts from fitting together closely before installing the mold. Then, formworks need to be oiled before the mixing process to prevent the mortar mixture from sticking to the mold. For split tensile strength test, 16 number of samples are required for 7 and 28 days which cylinder mold are being used for this experiment in the laboratory. The size of cubes for cylinder is 200mm for height and 100mm for diameter. Figure 2 and 3 shows the compressive strength test and split tensile strength test respectively.

Figure 2: Compressive strength test

Figure 3: Split tensile strength test

3. Results and Discussion

In this paper, result and analysis that were conducted in the laboratory are presented. The optimum percentage of alkaline activated CBA in mortar as partial cement were explained in detail.

3.1 Specific gravity

Table 2 shows the specific gravity of OPC and CBA. This proves that CBA has a benefit in lightweight materials since it has lower density compared to cement. The specific gravity value presents of CBA was lower than cement due to higher carbon content and lower iron oxide content [13]. The specific gravity of CBA also depends on the grinding periods. The longer the period time of grinding in the ball mill, the higher the specific gravity of the [14][15].This also proves that it needs to identify and understand the physical properties of the CBA after the grinding process.

Table 2: Specific gravity of OPC and CBA

Sample	Specific Gravity
OPC	2.67
CBA	2.61

3.2 Compressive strength test

From the Figure 4, summarized that the controlled sample get the highest strength value compared to other mixtures of alkaline activated CBA at the age of 3, 7 and 28 days. From the graph, it can be observed that the strength of 40% of alkaline activated almost reach the strength for the controlled sample which it can accelerate the setting time at the early strength development and decreased at the age of 7 days. While for the 20% of alkaline activated CBA shows that increasing strength as the age of days increased. For 60% of alkaline activated CBA, the strength of the mortar shows the smallest value compared to the others.

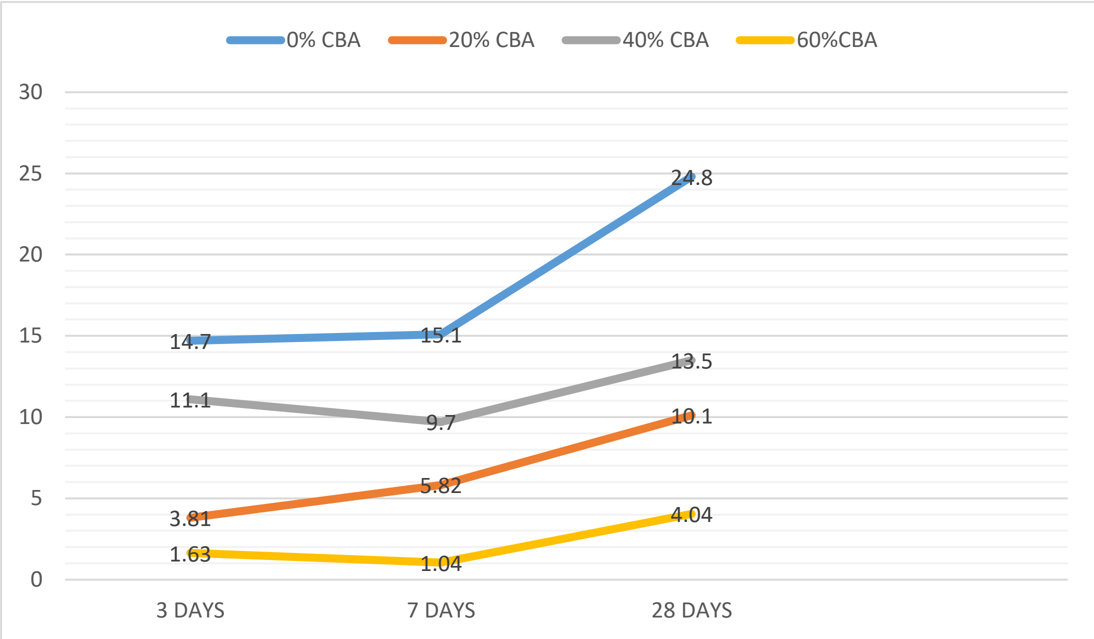

Figure 4: Compressive Strength test of Alkaline Activated CBA at age 3, 7 and 28 days

The optimum percentage to achieve the maximum strength is 40% of alkaline activated CBA as partial cement in mortar. However, the longer the grinding time of CBA, the higher the compressive strength of the sample due to the fineness particle of the CBA that can reduce the pore structure in concrete and reduce the packing structure [16]. The addition of $CaCl_2$ increased the strength contributed by dicalcium and tricalcium silicates. Furthermore, it increased the strength of cements up to 1 year [17]. At the early age of the alkaline activated CBA, the strength of the sample is very low compared to the controlled sample due to the pozzolanic reaction slowly which the cement in the mix for 28 days. Thus, the strength of the alkaline activated CBA is lower than controlled sample, they show the good improvements in strength due to the pozzolanic reaction.

3.3 Split tensile strength test

Figure 5 summarized the 40% of alkaline activated CBA shows increased strength of mortar at the age of 7 and 28 days. While the controlled sample and 20% of alkaline activated CBA shows the decreased strength of mortar. However, the 60% of alkaline activated CBA shows a small increased value of strength but not effective compared to the 40% of alkaline activated CBA.

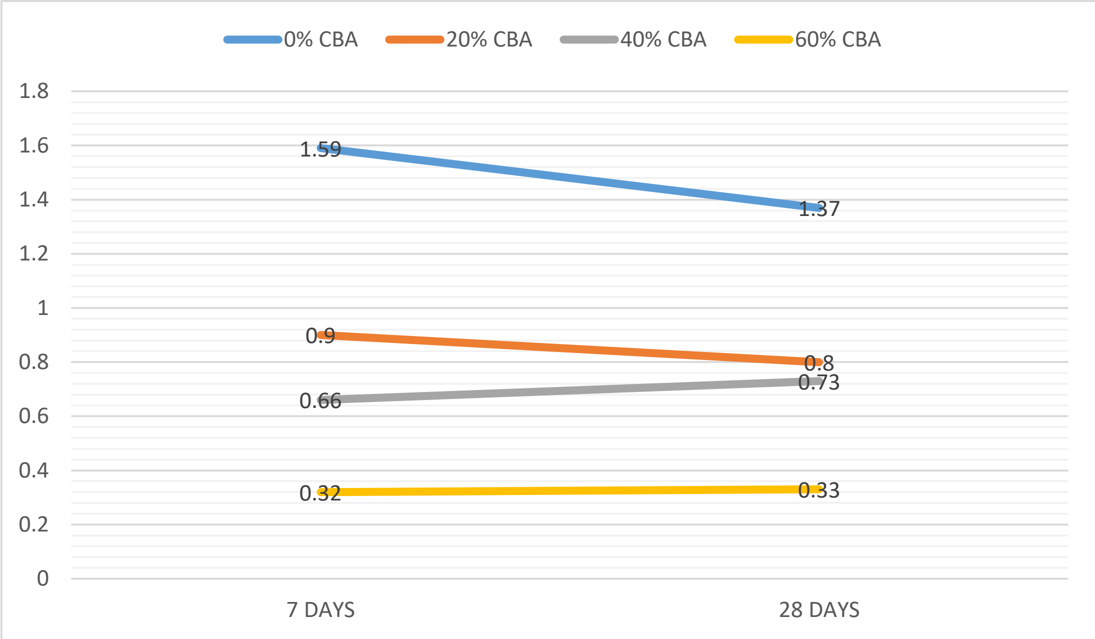

Figure 5: Split tensile strength test of Alkaline Activated CBA at the age of 7 and 28 days

According to *Williams et. al* [10], maximum strength of the mix with $CaCl_2$ were by 3% and considered as optimum replacement level in concrete mix. A further increase in $CaCl_2$ content decreases the split tensile strength of the mix. This proves that 4% addition of $CaCl_2$ can reach the target strength at 28 days which shows the good improvement for a mix in mortar. The result obtained from the graph did not reach the target due to human error which can be discussed as the size of particle or the properties of the CBA in this study cannot reach the potential to be as partial cement in mortar. the mixing or curing process may be default due to human error or random error. Temperature of the surrounding also affect the curing process of the samples.

The outcome, in my view, was not obtaining the desired result due to the value of the water-cement-ratio utilised. The greater the w/c ratio, the poorer the strength of the mortar, since too much water causes segregation and cavities in the mortar. The thermal gradient is also created by sudden temperature changes, which promotes cracking. Sulphate combines with calcium and aluminium ions in cement paste to create calcium sulphate and calcium sulphoaluminate hydrates, which account for the disrupted mix. There was evidence that the resistance to sulphate assault was diminished when $CaCl_2$ was added in the mix.

4. Conclusion

Based on the data analysis and the discussion that carried out for various percentages of the alkaline activated CBA as partial cement in mortar, some conclusions can be summarized based on the objectives of the study.

1. The particle size of the CBA depends on the grinding period of the CBA in the ball mill machine. The size of the particle become fine after the grinding process, and it increases the specific gravity of the CBA as well. Besides, the CBA cannot achieve the properties of the cement to bind the mortar and increase the mechanical strength of the mortar.
2. The various percentages of alkaline activated CBA in the mortar were changed the mechanical properties of the sample. $CaCl_2$ could improve the mechanical properties of the CBA as partial cement in respect to the control mixture due to the natural pozzolans.
3. For the compressive strength, the result shows that the strength for the alkaline activated CBA compared to the controlled sample was low and did not achieve the target strength due to the

pozzolanic reaction between the particle in the mortars and its fineness of the CBA to replace as partial cement and cannot react as the same properties.

4. Also, for the compressive strength, the alkaline activated CBA cannot achieve the target strength because of the porosity of the structure in the samples. This condition influence by the fineness of the particle of the CBA in the mortar.
5. For the split tensile strength test, it shows a positive result for the 40% alkaline activated CBA compared to other mixtures which shows the decreased strength. This may be due to the pozzolanic reaction in the mixture with the longer period of the age 7 to 28 days.
6. In a nutshell, this shows that the 40% addition of alkaline activated CBA is the optimum value for this study. It was observed from the mechanical properties that the 40% of alkaline activated CBA shows the better result compared to the other percentages of alkaline activated CBA. This can improve the economical and carbon dioxide emission and also decrease the environmentally friendly compared to the controlled sample. CBA is one of the most viable approaches to replace the material of the carbon dioxide emissions.
7. This is not only beneficial to provide the ideal solution by reducing the carbon dioxide emissions, but this will reduce the waste after the coal combustion.

As a conclusion, the combination of $CaCl_2$ and CBA have the potential to replace partial cement in mortar mix. The result obtained achieve the objectives of this study which to determine the optimum mix of the alkaline activated CBA as a partial cement in mortar.

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