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Mechanical and Chemical Properties of Coal Bottom Ash as Sand and Cement Replacement: A review

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Abstract: Sand and cement are the main materials in the production of concrete, but it must deal with the problem of environmental issue related to the material resources. The goals of this study were to review mechanical and chemical properties CBA as sand and cement replacement in concrete. Plus, this review will justify the best percentage of CBA to be used in concrete as the sand and cement replacement. Some past studies have been conducted on the function of CBA as the replacement of sand and cement. The studies were done through literature review from different researchers. In this review, the characteristics of CBA were reviewed on mechanical and chemical properties from the previous published journal. From the review, coal bottom ash has shown that it was a right material to be the substitution of sand and cement in concrete. Besides, the ideal percentage of CBA as the replacement of sand and cement was 10%- 25%.

Keywords: Mechanical, Chemical, Coal Bottom Ash, Cement Replacement

1. Introduction

Concrete is main substance for construction field. It is probably the most used building material in the world. The demand for concrete making sand is also an important material when doing construction. It need to use other waste material to change partially of the elements used for making the conventional concrete [1]. Industrial waste by-product made the researchers tried to explore and find an alternative way to use other than the natural resources. The benefit that can be expected, was the quality of concrete

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by using the industrial waste by-product. The outcome was almost the same as the conventional concrete.

The strength of concrete had been the interest of the researchers. To produce a durable concrete, a concrete must have high resistance to external agent that can damaging the concrete such as water. To get that such of resistance, the design criteria that affect the durability and strength of the concrete need to be concern. New material is a best solution to prevent and avoided the consumption of natural resource like sand. When using an alternative material, the effect on both mechanical and chemical characteristic were the main concern that need to be taken care of.

At the coal fired plant, CBA was produced. CBA is a result of combustion of coal fired plant. During the burning process, some tiny parts of the ash gathered on the walls and pipes and then fall to the bottom of boiler. The ash composed at the bottom of the boiler is called CBA. The CBA is also known as the additional materials used in concrete mixtures to increase workability of concrete [2] Next, the rising request for electricity established in the construction of many coals fired power plants. As the utilization of coal by power plants increases, so does the production of coal by product such as coal bottom ash. Although the consumption of coal increased, waste issues is linked with the coal production, and it is a serious problem that need to concern about. Malaysia is very strict about environmental matters, and it has caused the stringent control about the emission standards on the new projects for coal power. Removal of unused CBA is pricey and take a enormous problem on the power industry. Besides, the discarding of CBA in landfills bring to other problem. Referring to Environmental Protection Agency (EPA), living near to CBA dumpsite can give harm to human health and exposed to dangerous disease like cancer [3]. Plus, coal bottom ash disposal may create another harm that is environmental hazard.

Lately, many researches have revealed an attention in CBA as it carry lots of advantages to the construction industry [4]. Topçu and Bilir [5] have tried CBA to replace fine aggregates in concrete through different additional level to find differences on cracks because of porous structure. Some effect of CBA as the spare of the fine aggregates on the characteristics of concrete. The setting time will be affected by existence of the CBA[6]. Besides, the effect of consuming CBA as the substitution for the fine aggregates on the mechanical resources of concrete that is the strength of CBA concrete for variety ratios of CBA and can be distinguish from the strength of concrete for several days of curing [7]. Plus, CBA can swap the fine aggregate in production of concrete because the sand is expensive as it is long carrying distance from one place to another [8].

In summary, CBA is a good choice to replace sand and cement in the making of concrete [9]. Even so, there is an insufficient research for the characteristics of the CBA. Thus, this paper will review the mechanical and chemical properties of CBA as the sand and cement spare.

2. Materials and Methods

2.1 Materials

CBA is a material that did not burn when exposed to fire. The CBA shaped in furnaces of coal power plant [10]. The ash can be integrated into cement material and act like a binder. This is to change partial or totally of the sand and cement. CBA will act as a substitution of sand and cement in concrete [6]. Physical characteristics of coal bottom ash were like the natural sand and its particle size. The grading of CBA made researchers have an interest to explore the sand as a replacement material in the production of concrete [11]. Figure 1 shows the example of CBA.

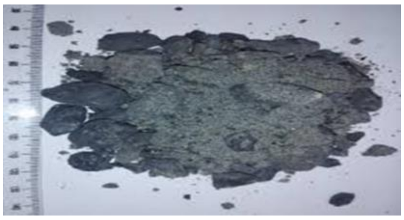

Figure 1. Coal Bottom Ash [3]

3. Result and discussion

In this study, all the outcomes and examination from the reviewed paper that had been directed. The ideal rate of CBA as the replacement of sand and cement are explained in detail.

3.1 Compressive strength

Compressive strength is the property that will be highlighted in this study for diverse proportions of CBA as the spare for sand and cement in concrete.

A current studies that conducted by Raju [12] was about the 7 and 28 day cube compressive strength of CBA concrete. The development patterns shown by CBA concrete at all the levels is like the control concrete. During the 7 days of curing, the concrete mixtures that containing of 5%, 10%, 15% and 20% of coal bottom as obtained 67.46%, 67.73%, 68.17% and 71.6% of their 28 days compressive strength. Besides, when linked to 28 days compressive strength gained by control concrete mixtures, it is only acquired 72%. Next, throughout the 28 days curing, the compressive strength of concrete blends holding CBA that replacing cement and sand has exceeded the reference concrete. During the initial of 7 days curing, compressive strength is the reasons that make the CBA concrete become strong at initial curing of 7 days because of the replacement of the material with the weaker material.

Based on Maliki [13] the compressive strength of CBA concrete mixes for 7 days decreased at 10% of CBA from 36.8 MPa to 32.8 MPa. Then, the strength increased gradually at 20% until 40% of CBA from 34.7 MPa to 35.2 MPa. At 50% of CBA, the strength of concrete dropped again to 33.4 MPa. Next, during 60% of CBA, the strength of the concrete value increased greatly up to 36.4 MPa and then decreased slowly till it gotten 100% of CBA in concrete. Besides, for the compressive strength of CBA concrete mixtures of 28 days also decreased at 10% of CBA from 45.6 MPa to 42.0 MPa. It then gradually increased at 20% until 40% from 43.1 MPa to 45.6 MPa. At 50% of CBA, the compressive strength dropped slightly to 43.5 MPa. At 60% CBA, the strength of concrete value increased up to 46.2 MPa and then decreased slowly until 100% of CBA in the concrete. The top portion to obtain the highest compressive strength for both 7 and 28 days were about 60% of CBA as sand and cement spare in concrete. The delay in hydration when using CBA as the sand and cement replacement can be the cause for the variable results accomplished in terms of optimal compressive strength.

From Singh [2], the strength of joint CBA and sand was lesser than the reference mix. The changes in strength at the age of 3 days and 7 days were 12% and 14.5% respectively.

According to Kurama [14] the compressive strength of coal bottom as mixtures of 7th days for 5%, 10%, 15% and 25% were 28.09 (N/mm^2), 28.22 (N/mm^2), , 26.47 (N/mm^2), and 19.79 (N/mm^2), while for 28th days, the strength were 40.38 , 40.24 , 33.57 and 29.13 (N/mm^2). The increasing amount of CBA replacement varies from 5% to 25%. The more addition of CBA than 10% will lead to a reduction in the compressive strength for all specimens. This decrease is much noteworthy for lower curing time such as 7 days.

Andrae [6] noticed that the compressive strength of 25%,50%,75% and 100% CBA mixtures for 7 days were 14.8 MPa, 11.8 MPa, 8.0 MPa and 5.9 MPa. For 28 days, the same amount of coal bottom ash from 25% until 100% was applied in the mixtures. The compressive strength varies from 23.2 MPa, 18.0 MPa, 11.5 MPa and 8.6 MPa. This shown that it had an increased in compressive strength than the control reference for both 7th and 28th days except for 25% CRT/CRT 4 in the 7-28 days interval

In summary, different researches found unlike optimum value of CBA as the sand and cement spare. Raju [12] stated. the optimum value of CBA was 60% while others decided that the optimum value of coal bottom ash as sand and cement replacement are around 10-25%. A high amount percentage of CBA used in mixtures will make a decline in the compressive strength. 5% of CBA replacement provides lower strength than control concrete. This is because of the replacement of material with weaker material. Plus, the absence of pozzolanic activity by the CBA contributed to that result.

3.2 Workability of concrete

The workability of concrete can be determined by using slump. Different percentages of CBA affected the result of slump.

Rafieizonooz [15] found that the value of controlled mix slump for C0, FBC1, FBC2, FBC3 and FBC4 were 73mm, 92mm, 76mm, 53mm and 37mm respectively. Coal bottom ash exhibited a huge-water absorption ratio than to the sand and cement material. Some of the water absorbed by the coal bottom ash. The spare level of ratios of CBA varied from 25%, 50%, 75% and 100%. Concrete mixtures of FBC1 and FBC2 has advanced value of slump that were 92mm and 76mm as compared to C0 (73mm). This is due to the existence of coal bottom ash with small percentages of CBA that fewer than 50% in the concrete mixtures. Besides, increasing of CBA on concrete blends FBC3 and FBC4 making the value of slump decreased when differentiate to reference mix concrete.

Aggarwal [7] recorded that the value of slump for 10%,20% and 30% of sand and cement replacement were 69mm, 62mm, 58mm, respectively. The workability of concrete varied when various proportions of CBA were added. Both 20% and 30% of CBA has lower slump value rather than 10% of CBA. The workability of concrete declined with the rising in the percentages of coal bottom ash in the concrete mixtures due to the increase in water demand.

Umar [16] noticed that the slump reference sample, 5%, 10%,15% and 20% of CBA were 55mm, 25mm, 40mm, 45mm, 15mm, respectively. The slump increased from 25mm at 5% of CBA to between 40- 45mm at 10%-15%. All percentages of CBA from 5%-20% had a smaller value of slump than the reference mix. This is due to the increase of 29 water content even though it had the same water ratio at constantly 0.48.

In summary, the slump value will decrease with the increasing of percentages of CBA. The optimum value for the percentages of CBA is between 10%-25% as a good slump value for a concrete should be located around 45 95mm. Table 4.2 shown the slump value of different coal bottom ash mixtures.

3.3 Tensile strength

The tensile strength is the extreme value of tensile stress that a substance can cope with before it become failure.

Ibrahim [9] recorded that the concrete density was changed due to water cement ratio. Variety of water cement ratio will produce various density of concrete. A low water cement ratio produced a huge density of concrete. Next, the tensile strength will decrease with an increase of water cement ratio. However, tensile strength will be reduced through an increased amount of percentage of CBA as the sand and cement replacement.

Next, Sandhya [17] found that during age of curing with 7, 28 and 56 days, the tensile strength decreased gradually over curing of age. As for 7 days of curing, it dropped from 2.91 (N/mm^2) of NC (0%) to 2.19, 1.99, 1.79, 1.72 (N/mm^2). At a higher age of curing, it made the concrete obtained a strong flexural strength while a higher percentage of CBA made strength received by the concrete decreased.

Besides, from P. Kadam [18] the control concrete for 7, 28, 56 , 112 days of curing were 3.07, 3.92, 4 and 4.11 (N/mm^2). During the 7 days of curing, the tensile strength increased from 5C until 20C then it dropped and maintained from 25C to 30C. 20C was the nearest tensile strength that likened to concrete control. Plus, it was the maximum of the tensile strength obtained once the CBA was added in concrete mixture.

Then, Rafieizonooz [15] stated that during the age of curing 7 and 28 days, all CBA mixes shown that the tensile strength was lowered than concrete control (C0). The tensile strength for FBC3 was the only one that exceeded concrete control (C0) with 1.99%. Even so, the tensile strength was almost the same with the concrete control as the age of curing increased from 91 to 180 days. The results can be in good spread of C-S-H gel and extra C-S-H gel because the usages of the portlandite by pozzolanic action of CBA.

In summary, the optimum ratio of CBA in concrete as the sand and cement was at 10-25%. Huge percentage of replacement will cause a decreased in the value of tensile strength. Only study from [15] shown that higher percentages of CBA replacement produced large tensile strength than concrete control. This is due to the present of pozzolanic activity by the CBA.

3.4 Flexural strength

Flexural strength shown about the resistance of a material against deformation.

Based on Sandhya [17], the flexural strength of dissimilar percentage of CBA were tested with curing ages with 7, 28 and 56 days. The flexural strength for 7 days of curing, decreased from NC (0%) of 10.45 (N/mm^2) to 9.30, 9.06, 9.01 and 8.90 (N/mm^2). At curing ages of 28 days, the similar thing happened as the tensile strength dropped from 11.20 (N/mm^2) to 10.50, 10, 9.72 and then to 9.4 (N/mm^2). At curing ages of 56 days, the tensile strength was dropped again. The dropped in tensile strength was with the increased of proportions of CBA as the sand and cement replacement in concrete. It is because of the poor interlocking between the aggregates.

Besides, P. Kadam [18] found that as the rate of CBA used in the concrete for the replacement of sand and cement increased, the flexural strength also will be increased. 20% of CBA used in the reference mix was the optimum ratios as it was the maximum strength for the flexural strength. The CBA concrete yielded lesser flexural strength than the concrete control. The reason is because of the bad interlocking between the aggregates.

Then, Kumar [19] recorded that, during curing ages of 7,14, 28 and 56 days of curing, the highest value for the flexural strength were 7.94 (N/mm^2), 8.80, 9.04, 9.24 (N/mm^2). While, the minimum flexural strength was 2.20 (N/mm^2), 3.10, 3.40, 4.27 (N/mm^2), at 7, 14, 28, and 56 days. If the replacement of CBA was exceeded more than 40%, the flexural will be decreased.

Next, according to Yang [20] as of 28 until 56 days, the flexural strength value for CBA concrete that containing 0, 25, 50, 75 and 100% level replacement rose with 13.8%, 11.1, 12.7, 14.9, and 9.6 respectively. The increased of flexural strength of CBA concrete during the ages of curing was because of pozzolanic reaction of CBA.

3.5 Chemical Properties

To know its chemical properties, XRF test was used. The test will reveal the main chemical substances such as aluminates (AI_2O_3), silicates (SiO_2) and iron oxide (Fe_2O_3).

Based on Zainal [21] the researcher found that silicates was only 68.9% in the coal bottom ash. The other chemical compound like iron oxide and aluminate were 6.5% and 18.67% respectively This made the total percentages of main chemical compound existed in the coal bottom ash was 94.07%.

For Kumar [19], the percentages of total main chemical compound was 95.18%. It consisted silicates which made of 68%, while aluminate was 25% and iron oxide was 2.18%.

Next, Andraede [6] stated that the percentages of main chemical compound increased up to 89.5%. The distribution of the percentages of main chemical compound for silicates were (50.46%), aluminates (28.35%) and iron oxide (10.69%).

Lastly, Rafieizonooz [15] found that the percentages of main chemical compound for aluminates, silicates and iron oxide were 18.1%, 45.3% and 19.84% respectively. The total percentages of these main chemical compound in the coal bottom ash were 83.24%.

In short, all researchers had the total percentages of main chemical compound that exceeded 70%. Based on ASTM C618 for chemical composition of coal bottom ash, class F of coal bottom ash is when the percentages of silicates, aluminates, and iron oxide are exceeding 70%. Thus, it can be decided that the coal bottom ash that have the properties of class F is very suitable replacement of sand and cement in concrete.

4. Conclusion

In conclusion, the optimum percentage of CBA as sand and cement spare has been concluded that were from 10% until 25%. The coal bottom ash properties studied such as mechanical properties and chemical properties shown that, CBA is the right and suitable replacement of the use of product like concrete in construction material.

From the compressive strength, it shown that at the early curing for compressive strength was low because of the spare material with low quality substance and the absence of pozzolanic activity by the coal bottom ash. Even so, the compressive strength of CBA will reach its optimum value at the age and 28th day. The best rate of sand and cement spare was at 10% - 25%. A higher proportion of CBA in concrete mixture will produce a low compressive strength of concrete.

Then, the workability of concrete was studied in slump value. An ideal value of slump will have 10-25% of CBA. A higher value for the percentage of coal bottom ash used will make the slump value decreased thus making it produce a less effective concrete to be used in the construction.

Besides, the tensile strength shown that it will be decreased if the water cement ratio has increased. But, when the rate of CBA increased, the tensile strength will be decreased. The optimum percentage of CBA was around 10%-25%.

Moreover, the flexural strength will be increased when the ratio of the CBA used enlarged. The best percentage of CBA was about 10%-25%.

Lastly, the chemical characteristic of CBA are aluminates, silicates, iron oxide. These are the main chemical compound that made up CBA. The difference value from the main chemical compound can be caused by the different geometry of the CBA itself as different researcher will use different location to get the CBA sample. The coal bottom ash is belonging to the common material for the use of construction which is very suitable to replace sand and cement in concrete.

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