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Effect of Lightweight Waste-Based Aggregate on Lightweight Concrete

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***Abstract:** This paper study the effectiveness of waste material from industrial by-product as lightweight self-cured concrete. Waste material involved in this study is coal bottom ash, oil palm boiler clinker and hydrogel from diapers. Coal bottom ash (CBA) used as a fine aggregate replacement whilst oil palm clinker (OPBC) added into the concrete mixture as partial replacement of coarse aggregate in order to produce lightweight concrete. In addition, hydrogel from disposable diapers was acted as self-curing agent. Different percentage of CBA as the fine aggregate replacement in concrete was used with the constant value of OPBC as coarse aggregate replacement. The result shows that the concrete sample containing 100% replacement of CBA has the lightest density as compared to other samples. In terms of compressive strength, the sample containing 40% replacement of CBA has similar compressive strength to control sample with reduction of the density of 22% when compared to the control sample. It is concluded that the recycling of CBA and OPBC as replacement material in lightweight concrete has good potential and also processing of CBA and OPBC to develop nano-material are the future potential of CBA and OPBC research for energy efficiency building.*

***Keywords:** Coal Bottom Ash; Oil Palm Boiler Clinker; Compressive Strength; Hydrogel; Concrete.*

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I. INTRODUCTION

Malaysia contributed 58% of world palm oil supply, therefore, by-product of the industry was increasing every year and utilization of oil palm industry by-product as concrete material can give benefit to the environment and promote sustainable development [1]. The previous study reported that solid wastes were obtained from palm oil extraction which is oil palm clicker (OPBC) and was utilized as coarse and fine aggregates in order to produce lightweight concrete with a density of 1440-1850 kg/m^3 [2]. In a thermal power plant, coal was used as the main source of fuel resources in order to generate electricity. Due to electricity demand, usage of coal become increasing and storage of CCPs such as fly ash and bottom ash become an issue. It is reported that 16% of total CCPs represent the production of coal bottom ash (CBA) [3]. CBA is the incombustible material which is unburnt deposits of the coal combustion process and was extracted at the bottom side of coal combustion furnace in a thermal power plant with a physical appearance more brittle than natural sand [4 - 6]. By replacing CBA as aggregate, the previous study has reported to increase the concrete compressive strength and decrease drying shrinkage with a significant effect on concrete flexural strength and modulus of elasticity [7- 10]. It also reported that CBA is a good medium for internal curing due to high porosity surface and tend to increase the capillary water absorption which extends drying time, reduce drying shrinkage and decrease the unit weight of the concrete [11-14].

Nowadays, disposable diapers became needs and statistics of waste disposable diapers increasing up to 3.7 million tons out of 166 million tons of total waste produce worldwide [15]. It is discovered that hydrogel that contains in disposable diapers has good potential as an internal curing agent for concrete other than the common option of curing such as curing membrane. The previous study has reported that hydrogel could mitigate the drying shrinkage and plastic shrinkage due to lack of curing [16]. In this study, OPBC and CBA were used in order to produce lightweight concrete with hydrogel as an internal self-curing agent.

II. MATERIAL AND METHODS

OPBC was obtained at Tuan Mee Oil Palm Mill located at Sungai Buloh, Selangor. In order to collect the OPBC, sieve process by using wire mesh was conducted and directly mixed with the concrete. OPBC was used as a full replacement of coarse aggregate (CA) in concrete.

CBA was obtained from Jimah Power plant located at Negeri Sembilan and dried under the sun in order to eliminate any

moisture content. CBA was used as partial replacement of fine aggregate (FA) with the replacement of 60%, 80%, and100%.

Hydrogel from diapers was mixed into the concrete during the mixing process with a constant water-cement ratio of 0.45. Sika Viscocrete 2191 was added into concrete as super plasticizer. The mix proportion of concrete was tabulated in Table 1. Samples with a size of (100mm x 100mm x 100mm) were prepared by using OPC as the main binder. The sample was remolded after 24 hours and place in room temperature storage room.

Table. 1 Mix proportion of concrete mixture

Mix No	OPC (kg/m^3)	CA (kg/m^3)	OPBC (kg/m^3)	FA (kg/m^3)	CBA (kg/m^3)	SP (kg/m^3)	Hydrogel (kg/m^3)
Control	420	596	0	837	0	8.4	0
CLCA40	420	0	596	502.2	334.8	8.4	21
CLCA60	420	0	596	334.8	502.2	8.4	21
CLCA80	420	0	596	167.4	669.6	8.4	21
CLCA100	420	0	596	0	837	8.4	21

Workability

Slump test was carried out to determine the workability of fresh state concrete. The test is conducted according to a standard of BS EN 12350-2:2009 [17].

Physical properties

Density test was carried out in order to measure the quantity of a substance per unit space as the concrete is lightweight concrete as according to BS 1881-114:1983 [18]. The test was conducted for each self-cured concrete of 3, 7 and 28 days on balance.

Mechanical properties

In this study, the compressive strength test was conducted according to BS EN 12390-3:2002[19]. The strength of concrete was determined for the age of 3, 7 and 28 days.

Drying shrinkage was carried out to determine the change of length that occurred in concrete specimen due to drying in the air as according to BS ISO 1920 -8:2009[20]. As all of concretes contain hydrogel full with water, contraction of concrete was occurring as the water depleted due to the hydration process. A prism sample with a size of 160 mm and 40 mm x 40 mm were cast and remolded after place 24 hours at room temperature. Shrinkage was measured up to 28 days by two points were attached on each of the prism at a gauge length of 100 mm to measure the distance (strain) between the points.

III. RESULTS AND DISCUSSIONS

Result

The results show the analysis of data from the experimental study. The result of slump test, density test, compressive strength test, and drying shrinkage was discussed as below.

Workability

The highest slump is CLCA40 with CBA replacement of 40% as shown in Fig 1. Meanwhile, the lowest slump is CLCA100 compared to other percentage of replacement. The flaky shaped of OPBC and porous surface of CBA has contributed to the workability of the concrete. This is due to OPBC and CBA, tend to absorb more water due to its porous structure.

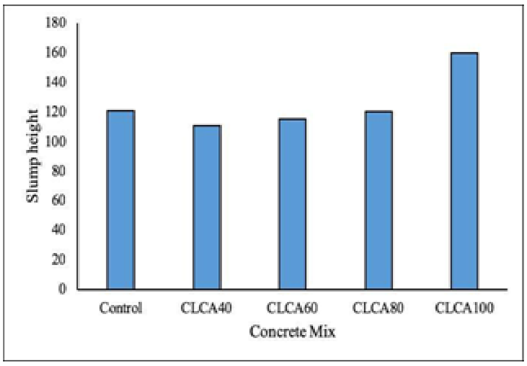

Fig. 1 Slump height of concrete mix

However, all of the slump value was comparable to control workability of concrete due to the presence of hydrogel and super plasticizer in concrete help to increase the slump value. The sample of CLCA40, CLCA60, and CLCA80 which contains hydrogel have higher slump compared to the control that further proving that hydrogel can improve the workability of concrete.

Physical properties

Fig 2 shows the density of concrete decrease as time passed. CLCA100 specimen that consists of 100% CBA as fine aggregates achieved 28-day density of 1434 kg/m^3. On the other hand, CLCA40 with 40% of CBA and 60% of sand as fine aggregates achieved 1864.46 kg/m^3. Meanwhile, CLCA60 and CLCA80 specimens achieved 28-day density of 1763.87 kg/m^3 and 1739.78 kg/m^3, respectively. Lastly, control mixture which was made from conventional aggregates and without the addition of hydrogel achieved the highest density which is 2280.78 kg/m^3.

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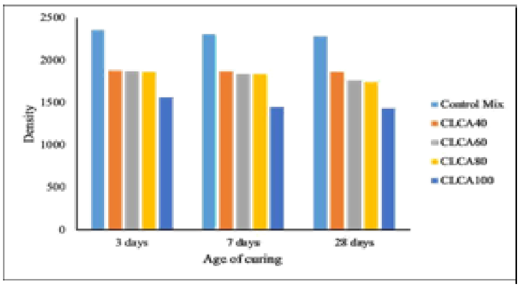

Fig. 2 Density of self-cured concrete

Mechanical properties

Fig 3 shows the compressive strength development of concrete with CBA and OPBC. The results displayed the compressive strength of 40% of CBA concrete was significantly similar compared to the control concrete. It was due to filler impact of OPBC aggregates and the pozzolanic reaction of CBA since it has a coarse surface area with well grading of particle size.

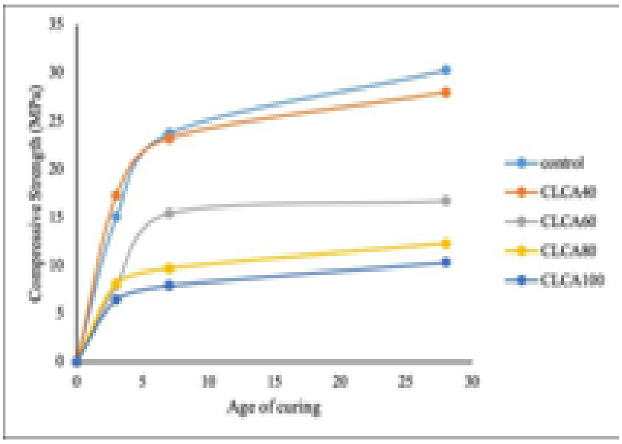

Fig. 3 Compressive Strength of self-cured

All OPBC and CBA concrete samples, with the replacement of CBA of 40%, 60%, 80% and 100% of fine aggregate, had a slightly different strength development in the early days. Strikingly, the result at up to 28 days showed that 40% of CBA has similar strength development as control concrete. Meanwhile, CLCA80 and CLCA100 show reduction up to 59% and 65% at 28 days of curing respectively. Moreover, CLCA60 strength development has reduced to 44% when compared to the control sample. Therefore, CLCA40 has given significant strength development when compared to the control sample. By fully replace CBA into the concrete; the sample achieved 23% of targeted strength however the density was reduced up to 32%. It was due to CBA has a porous surface and hydration process has taken place.

Drying shrinkage of all samples was tabulated in Fig.4, the trend showed that as the day passed by, the mass of shrinkage of sample reduced. This was due to exposure to the surrounding temperature that caused the evaporation process. The process of water loss followed by reduced in the volume of the sample known as shrinkage. Fig 4. shows the shrinkage results expressed in micro strain. As observed, the higher the replacement of CBA as fine aggregate, the higher the change in length. Drying shrinkage occurs when hydrogel in the concrete loss of its water due to the hydration process. In this study, drying shrinkage most likely to occur as the conventional way of curing method which involves the completely submerged of concrete in water.

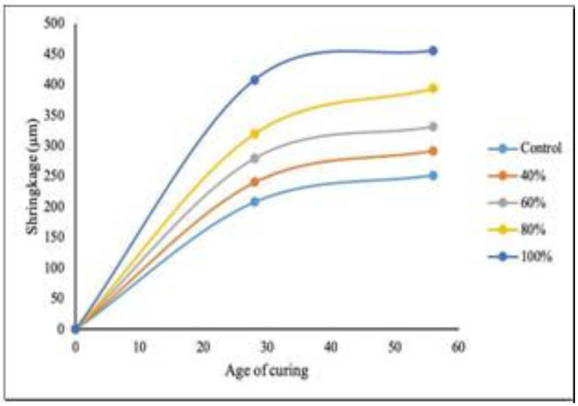

Fig. 4 Drying shrinkage of concrete

The main effect of shrinkage is the potential of cracking due to restraint. Restraint was due to internal factors of applied externally. The cracking tendency also affected by creep characteristic and modulus of elasticity. From the results obtained, shrinkage has higher chance to happen in the samples with a higher volume of CBA due to the finer water-filled capillary pores where the formation of curved menisci happened because of loss of moisture. Consequently, internal negative pressure was developed in the pores of the capillary. Shrinkage of concrete was triggered by compressive force resulted from the pressure. Further drying process was lead to loss of absorbed water.

The increase in attraction forces between the C-S-H hydration products causes a change of volume in unrestrained cement mixture. Moreover, samples with a lower amount of CBA tend to have lower shrinkage. This is due to the restraining influence of CBA is lower than sand. Other factors such as stiffness also contributed to the restraining influence. The results further clarified by the higher compressive strength achieved by concrete samples with the lower amount of CBA, they are difficult to compress thus, provide more restraint to the shrinkage. In addition, due to CBA has high water demand that explained why the restraining effect is greatly reduced.

Lastly, it can be observed that control samples experienced the least amount of shrinkage due to the conventional aggregates such as granite and sand have the different type of physical properties such as non-porous surface as compared to OPBC and CBA but does not give lightweight advantages to the concrete. The shrinkage reducing as decrease the drying shrinkage while maintaining its strength [21].

IV. CONCLUSIONS

This study was carried out to study the effect of OPBC and CBA as the aggregate replacement for lightweight concrete with enhancement of internal curing by using hydrogel on the behavior of concrete in order to significantly improve the concrete properties.

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The addition of OPBC, CBA, and hydrogel into the concrete mix had various effects on the properties of the concrete. Improvement in the drying shrinkage, density and compressive strength of the lightweight concrete samples was influenced by the percentage of replacement of CBA and the mix proportions that was used. The following conclusion was drawn from the study:

Concrete sample containing 100% replacement of CBA has the lightest density as compared to other samples. In terms of compressive strength, the sample containing 40% replacement of CBA has similar strength development to control sample with a reduction of the density of 22% when compared to the control sample. Lastly, drying shrinkage of the concrete sample containing 40% of CBA replacement with the inclusion of hydrogel gave the similar drying shrinkage to the control concrete. Therefore, it can be concluded that 40% replacement of CBA with the inclusion of OPBC and hydrogel has good potential as lightweight concrete also processing of CBA and OPBC to develop nano-material are the future of CBA and OPBC research for energy efficiency building.

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