Design Experiment for Leveraging Material Value Coal Ash as Material Mixture of Paving Block

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Abstract. The coal-fired thermal power plant is the main source of coal ash production. Coal ash collected at the bottom of the furnace (boiler) is called coal bottom ash (CBA) and fly ash remaining combustion called coal fly ash (CFA). In Indonesia, the utilization of bottom ash and fly ash generally is still limited to landfill material due to the value of the material too low. The objective of this research is to leverage the value of the utilization of bottom ash and fly ash materials as a mixer of construction industry products. Design of Experiment (DoE) was conducted on paving block product using various experimental factors such as composition of sand, cement, bottom ash, fly ash, and curing period of product. This Design of Experiment (DoE) applied orthogonal array to finding the best mixed compositions that affect the quality of the end result. After it, the proof was performed with a compressive strength test and water absorption test to meet the standard requirements. Testing compressive strength of paving block was done at 7 days, 14 days and 28 days to get the best result.

1 Introduction

Coal is one of the energy sources used in Indonesia, based on the 2015 estimate of power plants is an industry that ranks first as a coal user as a fuel. Once used in a burning medium (boiler), coal turns into fly ash (fly ash) and ash that falls into the bottom of the combustion chamber (bottom ash) [1]. The old paradigm regarding the utilization of fly ash and bottom ash as landfill hoarders due to too low the value of the material so it is not interesting to use again. Therefore, a new paradigm is considered to consider the leverage of fly ash and bottom ash materials by mixing with other materials to produce better construction products. Both types of materials are classified as waste electricity production, but research utilization is still relatively small. As for existing research, it only shows that fly ash and bottom ash can be used as a substitute material for cement and sand [2], but no one has shown the right experimental method to replace the material in producing the best quality, so research needs to be done to increase the value of performance on the value of economic efficiency.

This research aims to obtain the fly ash & bottom ash utilization as a paving block industrial product mixer which gives better material value and also seeks evidence of compliance with the Standard National Indonesia (SNI), and then calculates the performance that can be gained from the utilization of fly ash and bottom ash.

This research is limited to the use of fly ash and bottom ash for the construction industry which is used as raw material for paving block product substitution, with explanation of performance test result using laboratory test.

2 Material and Methods

1.1 Materials

The concrete prepared and tested in this study was composed of Ordinary Portland cement (OPC) ASTM C 150-04a, crushed sand (mixing stone ash & bangka sand), fly ash and bottom ash. Class F fly ash and Bottom ash were obtained from PT. Indonesia Power, Steam Power Plant Station, Lontar, Indonesia. The properties of CBA & CFA showed in Table.1 CBA was dried in an oven at a temperature of 110 C for three hours before use to ensure it is in dry state.

Table 1. Properties of fly ash and bottom ASH

FA	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	K ₂ O	Na ₂ O	SO ₃	MnO ₂	P ₂ O ₅	LOI
%	34,29	16,62	15,38	0,73	18,18	7,52	1,35	2,97	1,63	0,17	0,25	0,36
BA	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	K ₂ O	Na ₂ O	SO ₃	MnO ₂	LOI	
%	34,39	10,02	18,41	0,65	21,16	9,70	0,90	0,24	0,66	0,22	3,54	

1.2 Methods - Design of experiments

Various samples were prepared using different methodologies based on experimental design to predict the interaction component of the concrete mix. Experimental design is an important tool that can be used for product or process development and improvement [3]. In this study the effect of five control factors on the response, compressive strength of concrete, was investigated. All continuous variables were studied at 3 levels. Control factors levels used in this designed experiments were: % of cement mixing (5%, 20%, 30%), CFA (0%, 15%, 30%), sand (15%, 40%, 85%), CBA (0%, 70%, 85%) and length of curing period/age (7, 14, 28 days). Table 2 below summarizes factors considered along with number of levels and level settings.

Minitab 18.0 software is used create and design the DOE with orthogonal array method that resulted running in Table 3, summarizes the list of 27 sets of mixtures with 1 set replication that were prepared. Experimental results along with design matrix are tabulated. The order in which the experiments were performed was selected at random so that this design is completely randomized. The compressive strength of each of the samples was measured and evaluated for each case as the response variable.

Table 2. DOE factors

DOE Factors			
Factor	Level 1	Level 2	Level 3
% Cement	5%	20%	30%
% CFA	0%	15%	30%
% Sand	15%	40%	85%
% CBA	0%	70%	85%
Curing Period (Days)	7	14	28

Water content was adjusted until the required flow capability was achieved. The fresh mixture was then poured into paving mould of size (21cm x 10.5 cm x 6 cm), its top surface was leveled and kept covered with a wet cloth for two days in the laboratory condition after which the specimens were removed from the moulds and transferred to curing condition of 95% relative humidity at 22 C. The curing condition was achieved by keeping the paving block in partially water filled closed storage boxes and keeping the boxes in an air conditioned room as mentioned in [4].

Some nuisance (noise) factors were also identified, these are variables that probably have some effect on the response, but which are of little or no interest to the experimenter. They differ from held-constant factors in that they either cannot be held entirely constant, or they cannot be controlled at all. They include all composite batch-to-batch variation, and ambient temperature of the room and vibration of table while compaction and mixing. Other factors were predicted to exert some effect on the responses, but for the current study these factors are not of interest, so they have been held constant at a specified range. Examples of these factors include type of all composite, operator, water content in mix and cement to sand ratio. Table 4 outlines the noise factor and noise

management strategy of each one. A standard Hobart mixer was used for the mixing process.

Table 3. Orthogonal array result

	C1 Cement	C2 CFA	C3 Sand	C4 CBA	C5 Curing Period
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	1	3
4	1	2	2	2	1
5	1	2	2	2	2
6	1	2	2	2	3
7	1	3	3	3	1
8	1	3	3	3	2
9	1	3	3	3	3
10	2	1	2	3	1
11	2	1	2	3	2
12	2	1	2	3	3
13	2	2	3	1	1
14	2	2	3	1	2
15	2	2	3	1	3
16	2	3	1	2	1
17	2	3	1	2	2
18	2	3	1	2	3
19	3	1	3	2	1
20	3	1	3	2	2
21	3	1	3	2	3
22	3	2	1	3	1
23	3	2	1	3	2
24	3	2	1	3	3
25	3	3	2	1	1
26	3	3	2	1	2
27	3	3	2	1	3

Table 4. Noise factor and management strategies

Factors	Anticipated Effect	Noise Management Strategy
Operator experience and skill	High	Use one experienced operator
Water content	High	Water in the mix was limited to 0.5
Curing condition	High	Use same procedure for all experiment
Cement to sand ratio	High	kept at 1:3
Batch to batch variation	Low	Block & Randomization
Temperature of room effect	Low	Randomization

3. Result and discussion

3.1 Compressive strength

Results from the sets of experiments were investigated in more details for the compressive strength in Table 5. Fig. 1 shows the Pareto Chart of the factors affecting the

compressive strength. Using Cement% mixing and CBA% have the highest effect which will be illustrated further when discussing effect of each factor. The interaction of the age/curing time with CFA% and CBA% also has a major effect. Other factors can be seen from the Pareto chart in descending order of influence. As stated earlier there is no interaction between wet mixing and sonication time since not all the sonication times can exist for sand mixing, similarly between wet mixing and whisking and other 3rd and 4th order interaction terms.”

Fig. 2 illustrates the main effect plot of each of the factors studied. The effect of a factor is defined to be the change in response produced by a change in the level of the factor. Main effect is related to the primary factors of interest in the experiment. It can be seen that there is a non-linear relation between increasing the CFA & CBA and the gain in sample compressive strength compared to the control, indicating that adding more CFA & CBA does not necessarily result in a higher strength. As the age of the concrete increase, the compressive strength ratio also increases.

Table 5. Compressive strength

Exp No.	Cement (%)	CFA (%)	Sand (%)	CBA (%)	Curing Periods (Days)	Compressive Strength (MPa)		Mean	SNI Standard
						R1	R2		
1	25	0	75	0	7	4.13	5.52	4.83	N/A
2	25	0	75	0	14	5.53	5.1	5.32	N/A
3	25	0	75	0	28	8.51	8.75	8.63	Quality D
4	8.33	25	66.67	0	7	4.89	6.12	5.51	N/A
5	8.33	25	66.67	0	14	6.72	8.61	7.67	N/A
6	8.33	25	66.67	0	28	8.76	8.27	8.52	Quality D
7	2.45	14.63	41.46	41.46	7	17.12	19.04	18.08	Quality B
8	2.45	14.63	41.46	41.46	14	22.45	23.87	23.16	Quality B
9	2.45	14.63	41.46	41.46	28	27.13	26.52	26.83	Quality B
10	13.8	0	27.58	58.62	7	21.35	21.53	21.44	Quality B
11	13.8	0	27.58	58.62	14	27.04	29.11	28.08	Quality B
12	13.8	0	27.58	58.62	28	35.56	37.08	36.32	Quality A
13	16.67	12.5	70.83	0	7	20.56	20.44	20.50	Quality B
14	16.67	12.5	70.83	0	14	25.65	26.13	25.89	Quality B
15	16.67	12.5	70.83	0	28	33.34	35.07	34.21	Quality B
16	14.82	22.22	11.11	51.85	7	10.49	9.94	10.22	Quality D
17	14.82	22.22	11.11	51.85	14	14.78	15.42	15.10	Quality C
18	14.82	22.22	11.11	51.85	28	18.97	21.24	20.11	Quality B
19	16.23	0	45.94	37.83	7	15.82	17.1	16.46	Quality C
20	16.23	0	45.94	37.83	14	19.34	20.67	20.01	Quality B
21	16.23	0	45.94	37.83	28	24.45	25.66	25.06	Quality B
22	20.68	10.34	10.34	58.64	7	19.22	19.51	19.37	Quality B
23	20.68	10.34	10.34	58.64	14	27.67	26.41	27.04	Quality B
24	20.68	10.34	10.34	58.64	28	32.54	34.42	33.48	Quality B
25	30	30	40	0	7	5.66	5.95	5.81	N/A
26	30	30	40	0	14	4.33	5.74	5.04	N/A
27	30	30	40	0	28	7.56	8.63	8.10	N/A
28	15	0	85	0	7	5.94	6.13	6.04	N/A
29	15	0	85	0	14	7.47	8.01	7.74	N/A
30	15	0	85	0	28	10.96	12.04	11.50	Quality D

The best Compressive strength resulted from unproportional mixture with dominantly CBA is much higher than sand, and Cement higher than CFA (0%) as per experiment no 10 - 12. This is also influenced by other factors like curing period as illustrated in the interaction plot. This interaction was not captured by previous studies.

Fig. 1. Pareto chart of compressive strength.

Fig. 2. Main effect plot for compressive strength.

The findings of this study were investigated further by considering the interaction plot for compressive strength as illustrated in Fig. 3. In some experiments the difference in response between the levels of one factor is not the same at all levels of the other factor. When this occurs there is an interaction between the factors. Any crossing indicates an interaction between variables.

Fig. 3. Interaction plot for compressive strength.

To capture the above behavior, responses were modeled using response surface methodology as discussed earlier. Eq. (1) shows the model result for the compressive strength in terms of the process variables along with the goodness of fit. Quadratic terms, linear effects and interaction discussed earlier was captured through the model.

$$\begin{aligned} \text{Compressive Strength (MPa)} &= 28.158 + 4.833 \text{ Cement (\%)} + 0.335 \text{ CFA (\%)} - \\ &0.528 \text{ Sand (\%)} + 6.00 \text{ Curing Periods (Days)} \\ &+ 35.46 \text{ Cement (\%)*CFA (\%)} \\ &+ 29.24 \text{ Cement (\%)*Sand (\%)} \\ &+ 14.14 \text{ Cement (\%)*CBA (\%)} \\ &+ 1.846 \text{ Cement (\%)*Curing Periods (Days)} \\ &+ 51.37 \text{ CFA (\%)} \\ &+ \text{Sand (\%)} + 31.82 \text{ CFA (\%)*CBA (\%)} + 0.394 \text{ CFA (\%)} \\ &+ \text{Curing Periods (Days)} + 0.39 \text{ Sand (\%)*CBA (\%)} - \\ &0.181 \text{ Sand (\%)} \\ &+ \text{Curing Periods (Days)} + 9.49 \text{ Cement (\%)*CFA (\%)} \\ &+ \text{Curing Periods (Days)} + 10.68 \text{ Cement (\%)*Sand (\%)} \\ &+ \text{Curing Periods (Days)} + 5.12 \text{ Cement (\%)*CBA (\%)} \\ &+ \text{Curing Periods (Days)} + 10.93 \text{ CFA (\%)*Sand (\%)} \\ &+ \text{Curing Periods (Days)} + 6.58 \text{ CFA (\%)*CBA (\%)} \\ &+ \text{Curing Periods (Days)} - 1.49 \text{ Sand (\%)*CBA (\%)} \\ &+ \text{Curing Periods (Days)} \\ &\dots\dots (1) \end{aligned}$$

$$R^2 = 99.44\%$$

With anova (Analysis of Variance) result is:

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	19	2764.01	145.474	93.19	0.000
Linear	4	105.71	26.427	16.93	0.000
Cement (%)	1	56.07	56.073	35.92	0.000
CFA (%)	1	0.67	0.668	0.43	0.528
Sand (%)	1	1.86	1.864	1.19	0.300
Curing Periods (Days)	1	43.33	43.329	27.76	0.000
2-Way Interactions	9	1140.15	126.683	81.15	0.000
Cement (%)*CFA (%)	1	623.31	623.312	399.30	0.000
Cement (%)*Sand (%)	1	117.07	117.073	75.00	0.000
Cement (%)*CBA (%)	1	76.64	76.638	49.09	0.000
Cement (%)*Curing Periods (Days)	1	5.75	5.753	3.69	0.084
CFA (%)*Sand (%)	1	922.34	922.336	590.86	0.000
CFA (%)*CBA (%)	1	605.17	605.166	387.67	0.000
CFA (%)*Curing Periods (Days)	1	0.65	0.647	0.41	0.534
Sand (%)*CBA (%)	1	0.19	0.188	0.12	0.736
Sand (%)*Curing Periods (Days)	1	0.15	0.155	0.10	0.759
3-Way Interactions	6	46.40	7.733	4.95	0.013
Cement (%)*CFA (%)*Curing Periods (Days)	1	31.41	31.405	20.12	0.001
Cement (%)*Sand (%)*Curing Periods (Days)	1	10.99	10.991	7.04	0.024
Cement (%)*CBA (%)*Curing Periods (Days)	1	7.08	7.084	4.54	0.059
CFA (%)*Sand (%)*Curing Periods (Days)	1	29.39	29.388	18.83	0.001
CFA (%)*CBA (%)*Curing Periods (Days)	1	18.23	18.225	11.68	0.007
Sand (%)*CBA (%)*Curing Periods (Days)	1	1.89	1.889	1.21	0.297
Error	10	15.61	1.561		
Total	29	2779.62			

In the end, result of compressive strength will be compared with Standard National Indonesia (SNI). Mostly the result show that the compressive strength get the quality B of SNI with average compressive strength 20 – 35 MPa. For the best result showed by experiment No. 12 with 36.32 MPa that the including quality A (average 40 MPa).

3.2 Water absorption

The first procedure is Dry the specimen in a ventilated oven at a temperature of 105 °C to 115 °C till it attains substantially constant mass. And then, cool the specimen to room temperature and obtain its weight (M1) specimen too warm to touch shall not be used for this purpose. Immerse completely dried specimen in clean water at a temperature of 27±2 °C for 24 hours. In the end, remove the specimen and wipe out any traces of water with damp cloth and weigh the specimen after it has been removed from water (M2).

Water absorption, % by mass, after 24 hours immersion in cold water is given by the formula Eq. (2) Shows,

$$W = \frac{M_2 - M_1}{M_1} \times 100 \quad \dots \dots (2)$$

The final result shows by Table.6 and Fig 4. Water absorption for the mixtures ranged between 1.98% and 10.72%. The maximum water absorption for paving block under severe weather exposure is 17% whereas the same for paving block under moderate weather exposure is 22% [5]. Most of the paving block are found to have more water absorption values in this investigation. However these can be used in inner walls and situations of minimal weather exposure. Fig. 4 with implicit indicates the relationship between water absorption and BA/Cement ratio. It can be observed that the water absorption values for the mixtures with BA:FA ratio of 1:5 are the lowest. This is because bottom ash is not a water absorber as the percentage of bottom ash water

absorption is only 0.3–6.1% [5]. Yet fly ash is water absorbent material that increases the water absorption capacity of hardened matrix when it is used in the mix [6].

Table 6. Water absorption

Exp. No	Cement (%)	CFA (%)	Sand (%)	CBA (%)	Wet Mass (Kg)		Dry Mass (Kg)		% Water Absorption		Mean	SNI Standard
					R1	R2	R1	R2	R1	R2		
1	25	0	75	0	3.62	3.74	3.12	16.03	4.76	10.39	N/A	
2	8.33	25	66.67	0	3.42	3.48	3.14	8.92	9.43	9.18	Quality D	
3	2.45	14.63	41.46	41.46	3.56	3.65	3.44	3.49	3.99	3.74	Quality B	
4	13.8	0	27.58	58.62	3.62	3.58	3.54	2.26	1.70	1.98	Quality A	
5	16.67	12.5	70.83	0	3.68	3.7	3.48	5.75	5.41	5.58	Quality B	
6	14.82	22.22	11.11	51.85	3.68	3.71	3.41	7.92	8.48	8.20	Quality D	
7	16.23	0	45.94	37.83	3.62	3.66	3.38	7.10	7.65	7.37	Quality C	
8	20.68	10.34	10.34	58.64	3.41	3.38	3.32	2.71	3.05	2.88	Quality A	
9	30	30	40	0	3.63	3.64	3.36	8.04	13.40	10.72	N/A	
10	30	0	70	0	3.68	3.66	3.39	8.55	6.71	7.63	Quality C

Fig. 4. Main effect plot for water absorption.

4 Conclusion

Mixed results in literature about the influence of CBA & CFA on the mixture properties of paving block are very well justified since varying the procedure significantly affects the result. Depending on the procedure adopted, CBA & CFA can be effectively dispersed in the mix resulting in higher strength. This research compared the degree of variability that exists in concrete blocks from CBA & CFA dispersions when prepared using different protocols for the same cement to water ratio. Results clearly illustrates that for the purpose of data comparability, there is a need to provide the exact details of all steps involved in a dispersion protocol and an optimum protocol can be standardized.

From the data above, results of Compressive Strength & Water Absorptions show that experiment No.12 with the mixtures component Cement 13.8%, CFA 0%, Sand 27.58%, and CBA 58.62% in curing period 28 days give the best result and recommendation for production of paving block, of course also with concern the noise factor, but for the both influence composition CFA & CBA that showed exp. 24 with Cement 20.68%, CFA 10.34%, Sand 10.34%, and CBA 58.64% in 28 days. In the case experiment for industrial manufacturer, Orthogonal Array is very helpful because the company can reduce time and also reduce cost for to get the best result.

For the future work of the experiment, next researcher can mixture with the other sand types, add additive fluid

to composite and resetting DoE factor to get the best result. Researcher too can verify result of experiment with SEM (Scanning Electron Microscope)

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