THE INFLUENCE OF COMPACTION METHODS ON THE PROPERTIES OF HOLLOW CONCRETE BRICKS UTILIZING FLY ASH AND BOTTOM ASH

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Antoni[1], Manuel, E.[1], Sunarko, J[1] and Hardjito, D[1]*

[1] *Department of Civil Engineering, Petra Christian University, Surabaya, Indonesia*
**e-mail of corresponding author: djwantoro.h@peter.petra.ac.id*

ABSTRACT

This study focuses on the maximal use of industrial waste from burning coal, i.e. fly ash and bottom ash, in making hollow concrete bricks (HCB). Fly ash (FA) and bottom ash (BA) obtained from East Java, Indonesia, is incorporated to partly replace the use of Portland cement and natural sand. The purposes of the study are to determine the appropriate mix proportion incorporating the maximal use of waste products and to evaluate the effectiveness of three compaction methods, i.e. Manual, Vibration with load and Static compaction. This study is part of an effort to produce environmentally friendly construction materials for sustainable development. The optimum composition of the mixtures was found to be the use of 31% FA of the total binder and 24% BA of the total filler, with the filler-to-binder ratio of 8.6 by mass. Among the three compaction methods studied, it was found that the maximum compressive strength of 66.9 kg/cm^2 *was achieved when applying the Vibration-with-load compaction method with 3 layers, 7 second vibration period and 40 kg block weight. This compressive strength satisfies the requirement for Grade II concrete brick in accordance to Indonesian National Standard SNI 03-0349-1989. The water absorption of HCB produced from all the mixes was found small, less than 15%, satisfies the requirement of maximum water absorption in accordance to the standard.*

Keywords: Hollow concrete bricks, fly ash, bottom ash, compaction methods, optimum composition.

1. INTRODUCTION

The need for coal for generating power in Indonesia keeps increasing. For 2011, it is estimated that the figure is approximately 50 million tons [1]. This creates a challenge for waste management, as normally fly ash (FA) and bottom ash (BA) resulted from the coal combustion are only sent into landfill, and thus may create environmental threat. Out of the combustion of 50 million tons of coal, the ash produced will be around 4.9 million tons [2]. About 80% of it will be in the form of fly ash, while the rest is bottom ash. In East Java, Indonesia, a power station in Paiton produces approximately one million ton of ash annually [3]. Most of the fly ash is utilized by the cement company to produce Portland pozzolan cement, while the bottom ash is left unused in landfill. It requires more than 34 hectares of area as site for dumping the waste.

Bottom Ash (BA) normally does not possess any pozzolanic property in its non-ground form, which makes it unsuitable for use as ordinary Portland cement (OPC) replacement material in concrete. It might be used as mineral admixtures by grinding it into very fine powder or as fine aggregate (sand) replacement material [4]. However, Yuksel and Genc [4] informed that the use of BA as sand replacement in concrete reduces the compressive and tensile strength. Most probably, it is due to its porous characteristic that leads to the increase in water absorption ratio and to the weakened of the interfacial zone. Ten percent usage of BA as partial replacement for sand was recommended. Andrade et al confirmed that the use of BA as natural aggregate replacement in concrete may results in higher capillary absorption potential with water [5]. Water requirement increases rapidly when bottom ash is used in concrete [2].

Tarun Naik et al [6] reported the use of FA, BA and foundry sand in manufacturing concrete bricks and paving stones. They found out that the wet-cast bricks produced using up to 25% OPC replacement with FA and up to 70% natural sand replacement with BA and foundry sand could be used for both exterior & interior walls, whereas the paving stones could not be used according to ASTM requirements. Generally compressive strength decreased with the increase in the amount of the waste products incorporated. Meanwhile, Yuksel and Bilir [7] experienced that the use of BA is feasible up to 30% replacement of aggregates in production of briquettes.

Although the use of BA in making concrete may create some undesirable impacts, however the use of BA up to certain percentage shows great potential. The incorporation of fly ash as partial replacement of OPC may improve the properties of concrete due to its fineness and its pozzolanic properties, thus the use of both of them in concrete may compensate the adverse effect of utilizing BA. Moreover, the appropriate compaction scheme considering the behavior of BA may need to be set-up. Unfortunately, to date not much information is available on this topic.

This study was aimed to find out the optimal use of FA and BA from coal power generation plant in making hollow concrete bricks, and to elaborate the influence of several compaction schemes on its compressive strength and water absorption properties as required by relevant Indonesian Standard. The use of FA was aimed to replace parts of the cement as binder, and the use of BA was aimed to replace parts of the sand as filler.

2. METHODOLOGY

2.1. Materials

All the materials used were obtained locally in East Java. Fly ash (FA) was obtained from power plant in Paiton, while Bottom ash (BA) was obtained from Tjiwi Kima Plant in Mojokerto. The oxides composition of FA and BA are shown in Tabel 1. Portland Pozzolan Cement (PPC) used was from Gresik Cement, whereas the sand was obtained from sand quarry in Lumajang in two batches with the fineness modulus (FM) of 1.91 and 2.61 respectively. The fineness modulus of BA used was 0.96.

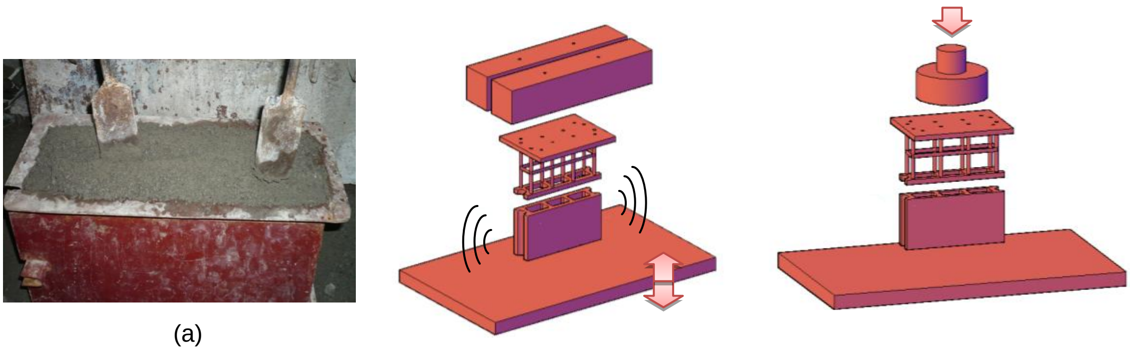
Tabel 1: Results of XRF analysis for Fly ash and Bottom ash

Oxide	Fe_2O_3	SiO_2	Al_2O_3	CaO	TiO_2	K_2O	MnO	BaO	Others	Total
Fly ash (%)	34.27	33.5	13	13	2.14	1.66	0.34	0.37	1.72	100
Bottom ash (%)	50.2	31	9.1	5.11	2.14	0.83	0.33	0.08	1.21	100

2.2. Experimental Design

Hollow concrete bricks (HCB) of 10×20×40 cm size was made to be tested. Steel mould was used to cast the concrete bricks with zero slump concrete, and the specimens could be taken out immediately after casting by opening the sides and removing the middle hollow mould parts. The mould and HCB specimen are shown in Figure 1.

Figure 1: Hollow concrete mould and brick



(a)

Figure 2: Compaction methods used:
(a) hand compaction, (b) vibration with load and (c) compression load

Before elaborating the influence of compaction methods, the optimum water content was to be determined so that the mix could have the maximum density while having enough workability to be compacted. This followed by the determination of the optimum filler/binder ratio and then the percentage of replacement by BA and FA successively, to obtain the optimum mix of the concrete mixture composition. The target strength was in accordance to Indonesian National Standard (SNI 03-0349-1989) [8], for grade IV concrete brick, with minimum compressive strength of 20 kg/cm^2.

Three methods of compaction was studied in this experimental research, namely; (a) Manual compaction using the steel hammer provided with the mould, as a baseline, (b) Vibration compaction with load on top of the specimen, and (c) Static compression using Universal Testing Machine (UTM) to apply various loads. The illustration of the compaction schemes is shown in Figure 2. The experimental design to obtain the optimum compaction method is shown in Tabel 2. The same FA and BA replacement ratio was used on the all concrete mixes to evaluate the effectiveness of the compaction methods.

Tabel 2: Experimental design for compression methods

Compaction Method	**Varied parameter**	**Fixed parameter**	**Test age**
Manual compaction	-	3 Layer	4, 28 days
Vibration with load compaction	No of Layers 2, 3, 4, 5	5 sec, 40 kg load	
	Time 3, 5, 7, 10 sec	3 layer, 40 kg load	
	Load 40, 80, 120, 160 kg	3 layer, 5 sec	
Static compaction	Load 10, 15, 20 KN	3 layer	

3. RESULTS AND DISCUSSIONS

Firstly, the optimum water content was to be determined. Figure 3 shows that the optimum percentage of water content is equal to 14% of total mass of solid. From the trial mixes, it was found that the water content in the range from 9% to 14% could produce a good compacted concrete, while the other values rendered the mixes too wet, hence caused segregation, or too dry and caused breakage when opening the mould.

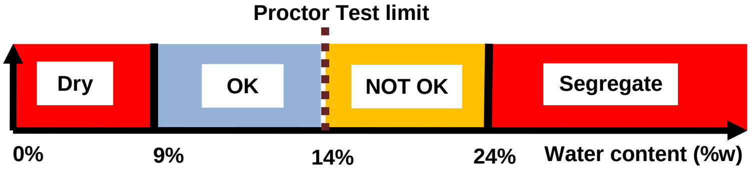


Figure 3: Measurement of water content for workable mix

The first series of the experiments was to determine the optimum filler/binder ratio in order to obtain the minimum compressive strength of 20 kg/cm^2. Figure 4 shows compressive strength of HCB with various filler/binder (f/b) ratios. Maximum compressive strength of 76 kg/cm^2 was obtained with f/b ratio by mass of 5.5; however this value is too high for normal HCB usage. The aim of this research was to produce a normal quality HCB with the maximal use of FA and BA as cement and filler replacement, thus only HCB strength of about 20 kg/cm^2 was needed. It was achieved with f/b ratio by mass of 8.57. With that f/b ratio determined, the maximum percentages of FA as binder replacement and BA as filler replacement need to be determined.

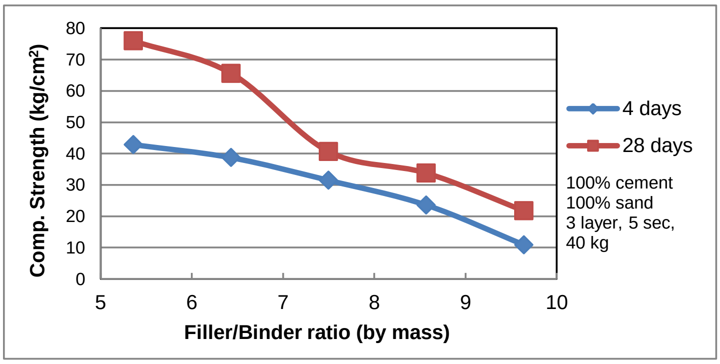


Figure 4: Compressive strength of HCB made by varying the filler/binder ratio

The compressive strength of the HCB with different percentages of BA as sand replacement is shown in Figure 5. At the age of 4 days, with the increase of filler replacement, it was shown that the compressive strength of HCB was reduced. However the reduction was not linear with the increase in BA content. At the age of 28 days, it was shown that the compressive strength was about 40 kg/cm^2 for 24% BA replacement, thus showing that there is a potential to incorporate BA up to 24% by mass of sand.

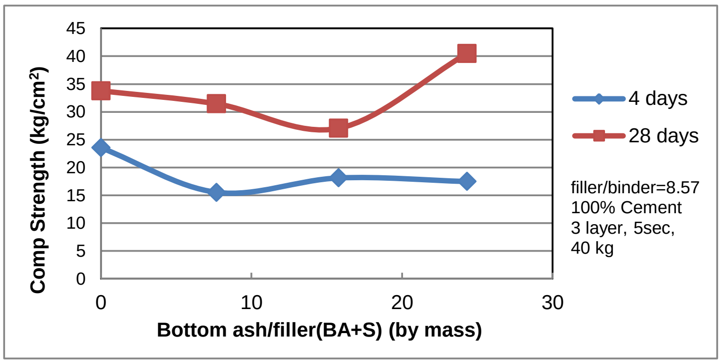


Figure 5: Compressive strength of HCB with different BA as sand replacement

Figure 6 shows the relation between the percentage of FA as binder replacement and the compressive strength of HCB. It is shown that the amount of FA incorporated into the mix does not cause significant reduction on the compressive strength. At the 8.5% content by mass of FA as binder replacement, it was shown that at the age of 4 days the compressive strength of HCB was higher than the 100% cement mix. This could be due to the improved workability because of small amount incorporation of FA. At higher percentages up to 31% OPC replacement by FA, it was shown that the compressive strength only experiences slight reduction, with the exception result at 15% replacement at the age of 28 days.

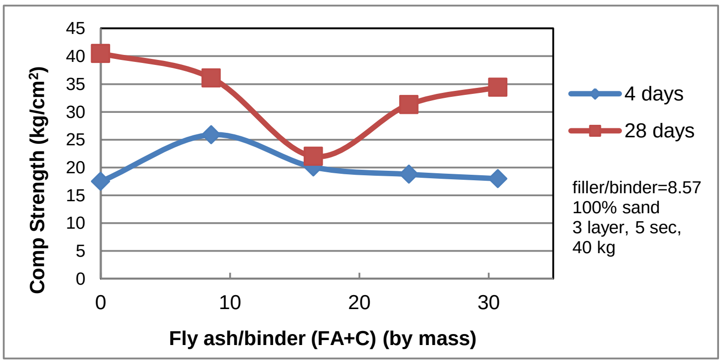


Figure 6: Compressive strength of HCB with different FA as cement replacement

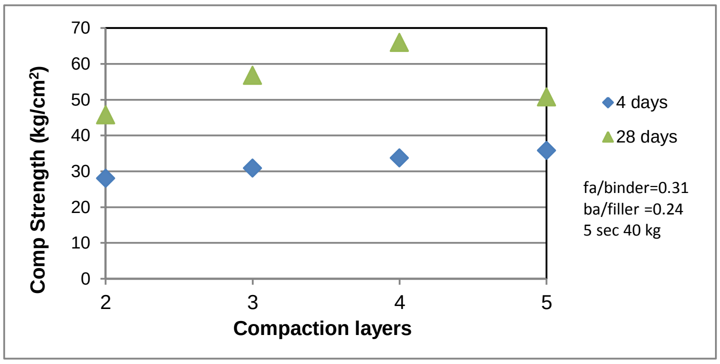


Figure 7: Compressive strength of HCB with varying compaction layers

To incorporate as much as waste materials as possible without causing harsh effect on the HCB, the cement replacement with FA was set at 31% of the total binder by mass and the sand replacement with BA was set at 24% of total filler by mass in the subsequent concrete mixes to study the effect of different compaction methods.

The effect of number of layers in Vibration-with-load compaction method on the compressive strength of HCB is shown in Figure 7. With the increase of number of layers, the compressive strength increased.

However, with 5 layers it seems that the 28 days strength was reduced. This could be due to higher number of layers causes over compaction and reduces the cohesiveness between layers. Four compaction layers seem to produce the highest compressive strength for HCB at 28 days.

The effect of vibration time on the compressive strength of HCB in Vibration-with-load compaction method is shown in Figure 8. There is an increase in compressive strength with the increase of vibration time, with the maximum compressive strength achieved at 7 second vibration with 40 kg load. Longer vibration time seems unnecessary, as shown that at 10 second vibration did not cause an increase in compressive strength.

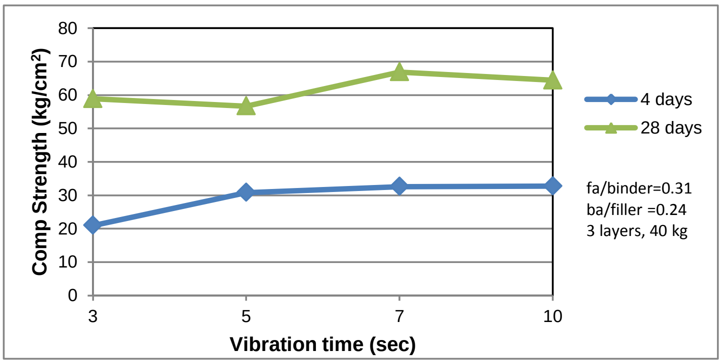


Figure 8: Compressive strength of HCB with varying vibration time

When varying the vibrating loads, the result was not linear with the increase of loading as shown in Figure 9. Higher loading tends to decrease the compressive strength. These results could be due to the design of the mould used in this experiment. Higher block weight increased the lateral pressure and the concrete mixes pushed out the side of the mould, resulted in lower compressive strength. It seems that loading with 40 kg block is sufficient to compact the concrete mix.

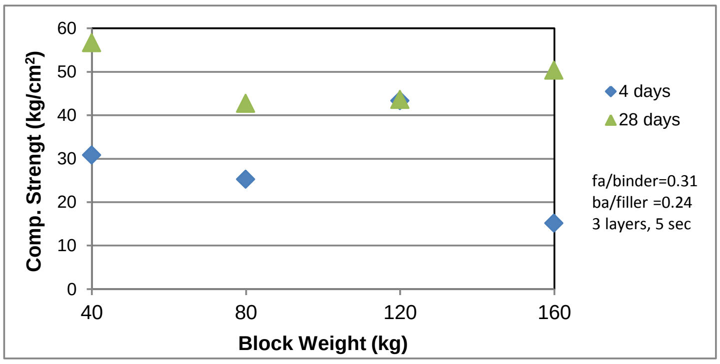


Figure 9: Compressive strength of HCB with varying vibrating load

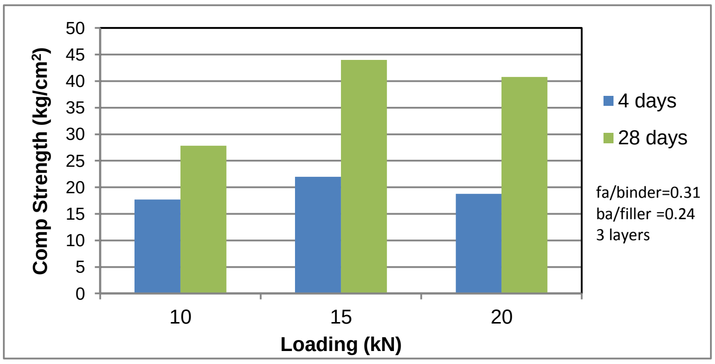


Figure 10: Compressive strength of HCB with varying static loading

The effect of static loading in Static Compaction method on the compressive strength of HCB is shown in Figure 10. With the increase of static loading from 10 to 15 kN load, it is shown that there is an increase of compressive strength. However at higher load of 20 kN, there is slight reduction in the compressive strength. The problem could be because of the design of the mould. This result is the similar to using higher vibrating load in Vibration-with-load compaction method, causing lateral load that cannot be resisted by the mould.

The summary of effect of different compaction methods on the compressive strength of HCB is shown in Figure 11. It is shown that manual compaction produced the lowest compressive strength of 19.8 kg/m^2, while the maximum compressive strength of 66.9 kg/cm^2 was achieved when applying the Vibration-with-load compaction method with 3 layers, 7 second vibration period and 40 kg block weight. This compressive strength is about 340% of that produced by the manual compaction method, and satisfies the requirement for Grade II concrete brick in accordance to Indonesian National Standard (SNI 03-0349-1989) [8], with minimum compressive strength of 50 kg/cm^2.

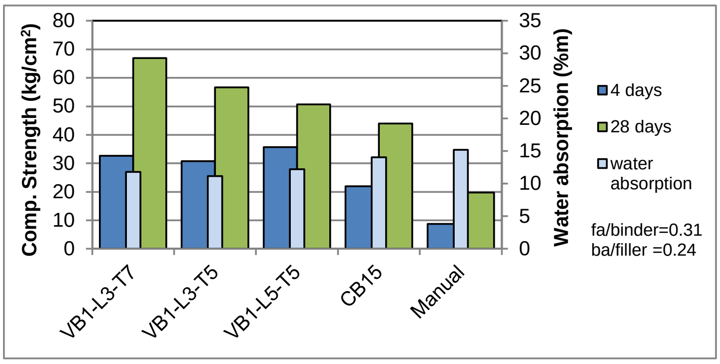


Figure 11: Compressive strength of HCB with different compaction methods

The water absorption of HCB from all the mixes was found small, less than 15%, with the amount is inversely proportional to the compressvie strength. The maximum requirement for water absorption of concrete bricks in accordance to Indonesian National Standard (SNI 03-0349-1989) [8] is 25% for Grade I and 35% for Grade II.

4. CONCLUSIONS

From this study, several conclusions can be drawn, i.e.:

1. The optimum composition of the mixtures incorporating FA and BA is found to be the use of 31% FA of the total binder by mass and 24% BA of the total filler by mass with the filler-to-binder ratio of 8.6 by mass.
2. Among the three compaction methods studied, it was found that the Manual compaction method produced the lowest compressive strength, while the maximum compressive strength of 66.9 kg/cm^2 was achieved when applying the Vibration-with-load compaction method with 3 layers, 7 second vibration period and 40 kg block weight. This compressive strength satisfies the requirement for Grade II concrete brick in accordance to Indonesian National Standard (SNI 03-0349-1989).
3. The water absorption of HCB produced from all the mixes was found small, less than 15%, satisfies the requirement of maximum water absorption in accordance to Indonesian National Standard (SNI 03-0349-1989), i.e. 25% for Grade I and 35% for Grade II.

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