Properties of Environmentally-friendly Concrete Bricks under Different Curing Regimes

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Abstract: This paper aims to evaluate the effectiveness of various curing methods on the properties of hollow concrete bricks incorporating fly ash and bottom ash resulted from coal combustion. Fly ash was used to partially replace the ordinary Portland cement, while bottom ash for the fine aggregates. The composition of the specimens tested was those with optimum composition, i.e. with 30% fly ash, 25% bottom ash, and with filler-to-binder ratio – all by mass - of 8.6. Curing methods evaluated were immersion into water, water spraying with different frequencies, spraying and wrapping with gunny sacks and lastly covering with plastic sheet to prevent excessive evaporation. The properties of hollow concrete bricks elaborated were the compressive strength, water absorption and density. It was found that spraying with water once a day resulted in the highest 28th-day compressive strength of more than 70kg/cm^2, which is attributed as Grade I hollow concrete brick in accordance to the relevant Indonesian standard. All of concrete brick specimens showed favorable water absorption properties.

Keywords: Curing Methods, Hollow Concrete Bricks, Fly Ash, Bottom Ash, Properties.

1 INTRODUCTION

Concrete bricks are common construction materials for walls and partition in Indonesia and many other countries. The conventional contents are sand, ordinary Portland Cement (OPC) and water. Basically, it is easy to made, and thus it is widely used.

Sustainable development is a challenge to materialize development in more harmonious way, to meet our needs today without sacrificing the ability of the future generations to meet their own needs. This might be practiced by using high performance materials at a reasonable cost with the lowest possible environmental impact.

Coal combustion remains popular choice to generate energy. For 2011, it is estimated that the need for coal to generate energy in Indonesia is approximately 50 million tons (PME, 2010). Most of the fly ash (FA) and bottom ash (BA) resulted from the coal combustion are normally disposed off into an open area or ash pond on the surrounding of the plant. Out of the combustion of 50 million tons of coal, the ash produced will be around 4.9 million tons. About 80% of it will be in the form of FA, while the rest is bottom ash (Gafoori and Bucholc, 1997). In East Java, Indonesia, a power station in Paiton produces approximately one million ton of ash annually. 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.

Lowering the use of natural resources and utilizing the waste products for construction materials is becoming a necessity. Although BA does not normally possess any pozzolanic property in its non-ground form and thus unsuitable for use as OPC partial replacement material in concrete, it might be used as fine aggregate (sand) replacement material (Yuksel and Genc, 2007). However, its porous characteristics leads to some undesirable impact, such as reduction in the concrete compressive and tensile strength, causing higher capillary absorption potential with water and increase the need of water. Nevertheless, previous studies recommended that the use of BA as partial replacement for sand up to 30% is feasible to produce briquettes (Yuksel and Bilir, 2007), and even up to 70%, in combination with the use of foundry sand, to manufacture concrete walls, for both exterior or interior usage (Naik et al, 2004).

In this study, BA was used in combination with FA. BA was utilized as partial replacement for sand, while FA for cement. The incorporation of FA was aimed to compensate the drawback of using BA through its pozzolanic properties, spherical shapes and its fineness.

This study aims to analyze the effect of different curing regimes to improve the quality of hollow concrete bricks. Four curing methods were evaluated, i.e. immersion into water, water spraying with different frequencies, spraying and wrapping with gunny sacks and lastly covering with plastic sheet to prevent excessive evaporation, with those undergone no curing served as reference. As not much information is currently available, this study is important to carry out to ensure that producing high quality environmentally-friendly hollow concrete bricks is a possibility.

2 EXPERIMENTAL PROGRAM

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 Kimia Plant in Mojokerto. The oxides composition of FA and BA are shown in Table 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.

Table 1. Results of XRF analysis for Fly ash and Bottom ash

Oxide	Fly ash (%)	Bottom ash (%)
SiO_2	33.5	31.0
Al_2O_3	13.0	9.1
Fe_2O_3	34.3	50.2
CaO	13.0	5.1
TiO_2	2.1	2.1
K_2O	1.7	0.8
MnO	0.3	0.3
BaO	0.4	0.1
Others	1.7	1.2
Total	100.0	100.0

2.2 Experimental Procedure

Hollow concrete brick (HCB) specimens of 100×200×400 mm size were made to be tested in this experimental work. Steel mould was used to cast the HCB 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. The percentage of water content to dry mix used was 9 to 14%, as determined in the previous experiment as the optimum water content (Antoni et al, 2011).

Before elaborating the influence of curing methods, the optimum water content was to be determined to allow the mix to have maximum density while having the required workability. This was followed by the determination of the optimum filler-to-binder ratio and the optimum amount of BA and FA, to obtain the optimum concrete mixture composition. The performance of the HCB produced was to conform to the relevant Indonesian National Standard (BSN, 1989), with minimum compressive strength of 20 kg/cm^2 for grade IV concrete brick.

This optimum mixture composition was employed to cast all of the HCB specimens. Vibrating table with load of 40 kg was used to compact the specimen in 3 layers, as this method was found to be the most effective compaction method for HCB (Antoni et al, 2011). The illustration of the compaction schemes is shown in Figure 2.

Figure 1. Hollow concrete mould and brick.

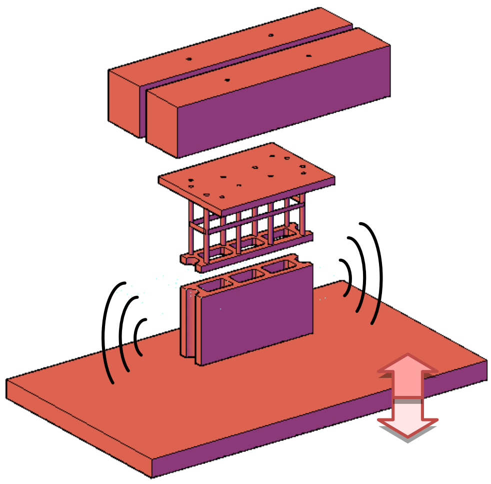

Figure 2. Compaction method using vibration with load.

Curing methods evaluated in this study were water spraying with different frequencies per day, immersing in water, water spraying and covering with wet gunny sack; and water spraying and covering with plastic sheet. The frequency of water spraying was varied as once, twice, three times and four times per day. All of the curing regimes were applied up to one day before testing.

3 RESULTS AND DISCUSSION

3.1 Determination the Optimum Mixture Composition

The first step was to determine the optimum sand-to-cement ratio for the base mixture with no incorporation of BA and FA. Results of the compressive strength of HCB with various cement-to-sand ratios are shown in Figure 3. The mixture chosen as the base mixture was the one with compressive strength slightly higher than 20 kg/cm^2 after four days, complying with type IV concrete brick according to SNI 03-0349-1989. Mixture with sand to cement ratio of 8.57, producing compressive strength of 23.55 kg/cm^2 after 4 days and 33.77 kg/cm^2 after 28 days, was chosen for the succeeding experimental program. This proportion is similar to the common practice in industry. The sand used in this series was the one with FM 1.91.

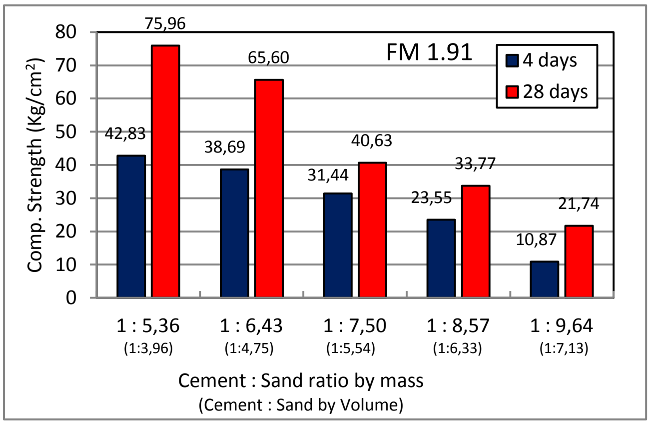

Figure 3. Compressive strength of HCB with different cement to sand ratios

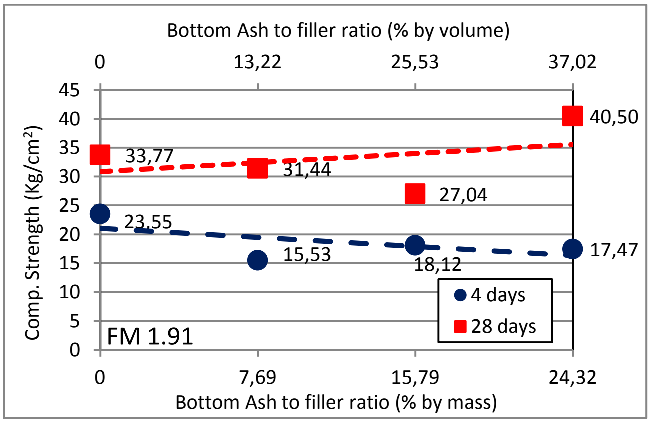

Figure 4. Compressive strength of HCB with different bottom ash to filler (aggregate) ratio

The next step was to determine the amount of BA to be incorporated as partial replacement for sand. Figure 4 shows that the more the percentage of bottom ash used to partially replace sand as filler material, the strength was reducing, with the exception of using 24.32% replacement at the age of 28 day. The tendency shows that with about 25% usage of BA for sand replacement, it is possible to obtain at least 20 kg/cm^2 compressive strength after 28 day. As the motivation of this study is to elaborate the maximal use of waste to produce quality HCB, the BA usage of 24.32% was taken for the successive series of mixtures in this experiment. In this series, 100% cement was used as cementitious material, while sand was the one with FM 1.91.

Next was the determination of fly ash ratio as partial replacement for cement. Figure 5 shows the compressive strength of HCB containing 24.32% BA versus fly ash to cementitious material (fly ash plus cement) ratio. As expected, the increase in FA content decreases the compressive strength due to slow pozzolanic reaction. However, the utilization of about 30% FA shows that the HCB produced still comply with the relevant standard. For the rest of the experimental work, the level of cement replacement by FA was taken as 30.72%, while the level for sand replacement by BA was of 24.32%, all by mass.

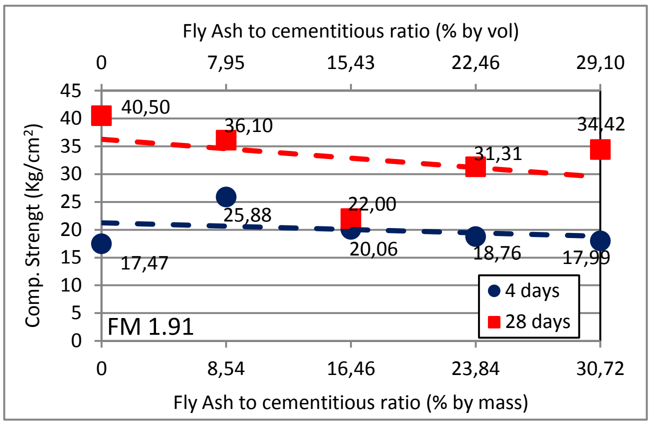

Figure 5. Compressive strength of HCB with different fly ash to cementitious ratios

3.2 Evaluation of Curing Regimes

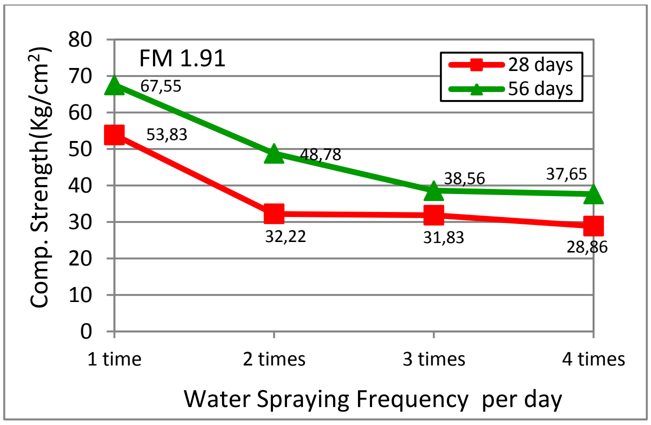

Figure6. Compressive strength of HCB with different frequency of water spraying per day with FM 1.91 sand.

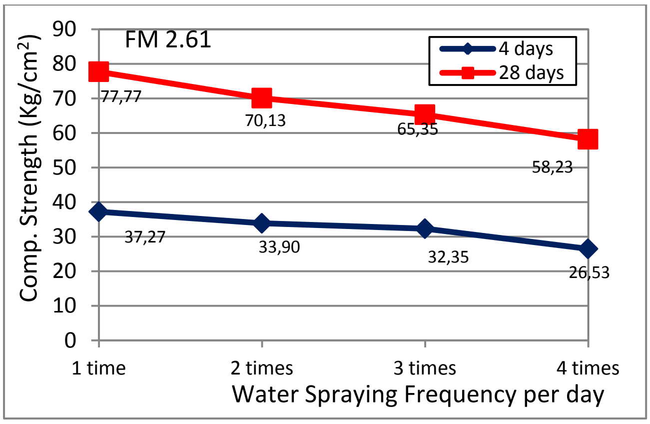

Figure 7. Compressive strength of HCB with different frequency of water spraying per day with FM 2.61 sand.

Both Figures 6 and 7 show the compressive strength of HCB with different frequency of water spraying per day. The difference between the two is only the Fineness Modulus (FM) of the sands used in the mixture, while the mixture composition was kept constant. Figure 6 shows those with FM 1.91 sand, while Figure 7 shows those with FM 2.61 sand, which is coarser than the previous one.

The use of coarser sand yielded significantly higher strength, especially after 28 days. Most probably, coarser sand caused better gradation of the aggregates, and thus better compaction was resulted with less water needed for making a workable mix

Figures 6 and 7 show consistent tendency on the effect of water spraying on the HCB specimens. The lesser the frequency of water spraying, the better the compressive strength. The fundamental of the phenomenon is still not known yet. HCB specimens have been cured until one day before testing. Most probably the specimens that have been undergone higher frequency of water spraying require longer time to drain off the moisture before time of testing. However, this gives favorable indication as the least effort of curing yields the best mechanical properties of the HCB.

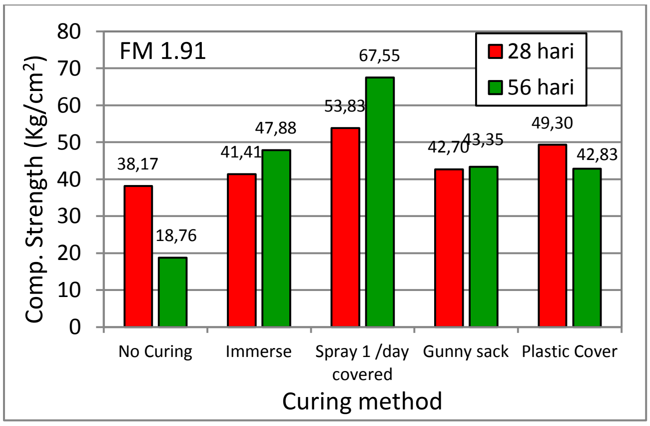

Figure 4. Compressive strength of HCB resulted by various curing methods after 28 and 56 days with FM 1.91 sand.

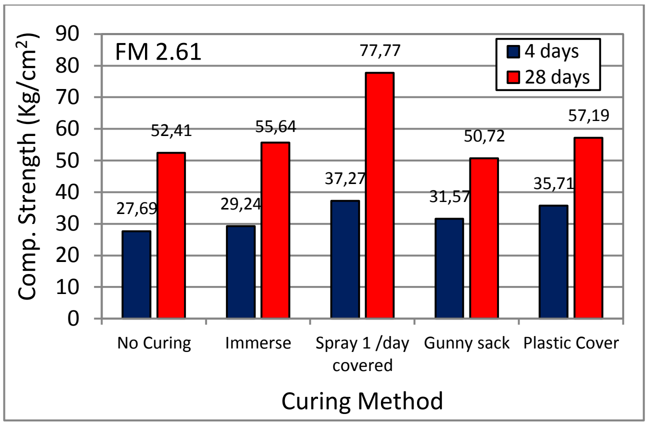

Figure 9. Compressive strength of HCB resulted by various curing methods after 4 and 28 days with FM 2.61 sand.

Figures 8 and 9 both show the comparison of compressive strength of HCB cured under various curing regimes. Figure 8 is the one with FM 1.91 sand, tested after 28 and 56 days; while Figure 9 is the one with FM 2.61 sand, tested after 4 and 28 days.

HCB specimens tested at 28 and 56 days did not really show significant difference in terms of compressive strength, although those cured by spraying of water once a day showed a strength development about 25%. Curing by spraying of water once a day proved to be superior compared to those cured by other regimes. Figure 9 even shows that by using sand with FM 2.61, HCB specimens cured under this curing method exhibit compressive strength higher than the minimum requirement for Grade I concrete bricks in accordance to the relevant Indonesian Standard.

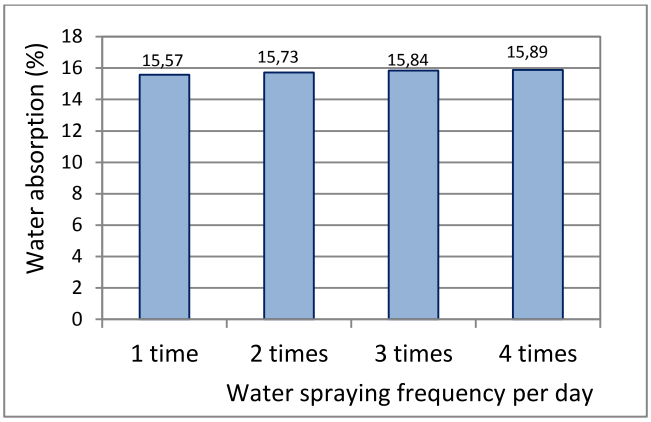

Figure 10. Water absorption of HCB specimens cured under different frequency of water spraying per day

Figure 10 shows the water absorption of HCB specimens cured by spraying water. All of specimens under different frequency of water spraying show similar and favorable results, with water absorption well below the requirement for Grade I concrete bricks according to the relevant Indonesian standard, i.e. 25%. The same information can be drawn from Figure 11, as all specimens cured under various curing methods show low level water absorption, well below the maximum requirement stated for Grade I concrete bricks.

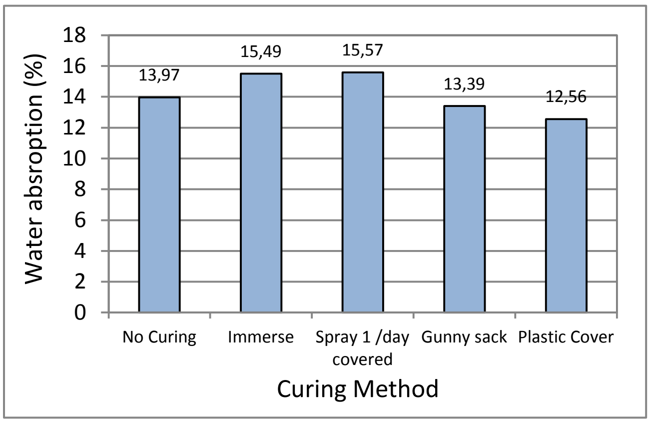

Figure 11. Water absorption of HCB specimens cured under different curing methods.

4 CONCLUSIONS

The optimum mixture composition of HCB utilizing BA as partial replacement for sand and FA as partial replacement for cement is that of 30% FA and 25% BA, with aggregate (sand + BA)-to-cement ratio of 8.6, all by mass.

Curing of HCB specimens by water spraying once a day was found to be the most effective, as it requires the least effort and yet it yields the highest compressive strength of 78 kg/cm^2 and low water absorption. This study shows that environmentally friendly and excellent quality hollow concrete bricks (HCB); produced by incorporating substantial amount of industrial waste; is a possibility.

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