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Research Paper

The Effect Of Thermal Activation Time And Different Composition Of Bamboo Ash On The Compressive Strength Of High Volume Mortar

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ABSTRACT

Since, one of major contributor to CO_2 emission is cement production, it affected to climate change and global warming. This environmental problem will most likely be increased due to exponential demand of Portland cement. A growing number of concrete productions per year will lead to increase manufactured cement significantly. Since, one of major contributor to CO_2 emission is cement production, it affected to climate change and global warming. This environmental problem will most likely be increased due to exponential demand of Portland cement. The utilization of agricultural waste is one breakthrough solution in Indonesia. The use of 50% Bamboo ash shows higher than the mortar used 100% OPC.

1. Introduction

Nowadays, the cement industry is direct to be environmentally-friendly. It is due to a magnitude number of mortar and concrete used in construction all over the world. In 2013 (Fig. 1), 4 billion tons of cement produced, as estimated concrete production exceed 4,000 million tons annually [1]. A growing number of concrete productions per year will lead to increase manufactured cement significantly. Since, one of major contributor to CO_2 emission is cement production, it affected to climate change and global warming. This environmental problem will most likely be increased due to exponential demand of Portland cement. By 2050, demand is expected to rise by 200% from 2010 levels, reaching 6000 million tons/year [39]. To eliminate the effect of OPC production on climate changes, the use of Portland cement and non-renewable materials should be reduced. In recent years, blended cement with pozzolanic or supplementary cementitious materials is widely used in cement and concrete construction by replacing part of cement [2, 3, 11]. The main reasons for using this kind of alternative materials are environmental, economic, or technical benefits. Mineral admixtures such as fly ash (FA), rice husk ash (RHA) and silica fume (SF) are silica-based pozzolanic materials and renewable so they can partially replace by Portland cement [4]. The kind of alternative material that is used often depends on the availability and on the field of application [9]. However the common alternative materials used include FA. The utilization of

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mineral admixtures improved the compressive strength, pore structure, and permeability of the mortars and concretes with time [4-5]. This is because the total porosity decrease with increasing hydration time [4-7].

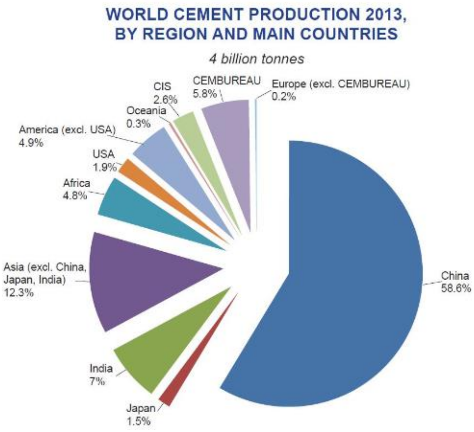


Fig.1 The cement production around the world in 2013 [1]

There are many reports [2, 4, 7, 11, 12, 17] that investigated the use of waste and by-product materials as pozzolan in cement replacement. The use of pozzolan as supplementary cementitious materials has been found to provide a visible enhancement on the mechanical properties of mortar. Furthermore, the mitigation damage of mortar became particular concern for durability of cement-based materials. Aldea et al. [2] mentioned two technological developments which can improve the ability of the material to maintain ecological processes in the future. They are the incorporation of several artificial waste materials into the concrete mortar and the use of a superplasticizer (SP) into mix design. Bagel [4] and Boubitsas [7] supported the previous statement by conducting a study about the effect of binary and ternary blended cement on mortar. For instance, the high level portions of slag and silica fume used in the binding system cause the mortars reached relatively satisfactory level of compressive strength and contributed to the significantly denser pore structure [4]. In 2001, Boubitsas [7] evaluated the effect of binary blended cement mortar containing 45% (by mass) GGBFS and 55% OPC with presence of 1%superplasticizer. The results obtained possess the highest improvement of mechanical properties, hydration kinetics and microstructure of hardened mortar. Several reports also explained the technical details for low and moderate level replacement of mortar [8, 11-13]. The percentage of low and moderate for cement replacement levels are 5% to 40% by mass, respectively [11]. In addition, Agarwal [12] has reported that 10% by mass replacement of pozzolan mortar, the compressive strength obtained was 18 MPa in 7 days and 25 MPa in 28 days. Karim et al, [13] investigated a set of mortar specimen which was made with 40% of natural pozzolan as cement replacement. The compressive strength result for 90 days reach up to 39 MPa under constant 40ºC temperature for 6 h hot water curing. On the other hand, high volume replacement levels of cementitious material have been an interesting topic for research and also industry. There is a little information focusing on the use of high volume cementitious materials as a cement replacement [8, 9, 10,14]. Varga et al, [8] evaluated properties of mortar containing high volume of type C fly ash under standard curing. Test results indicated that the use of 40% (by mass) type C fly ash in mortar increased at the early age day compressive, but reduced the modulus of elasticity. However, all these strength properties and abrasion resistance showed continuous and significant improvement at the ages of 190 and 365 days, which was most probably due to the pozzolanic reaction of FA at later ages. It was concluded that Class C fly ash can be suitably used up to50% level of cement replacement in mortar for use in precast elements and reinforced concrete construction. Herera et al.,[9] studied concrete were produced with mass substitution of cement by fly ash up to 75%. They concluded that using this level of fly ash was not effective to gain the strength of concrete. Then, Sajedi and Razak [14] make an experiment using high volume replacement levels up to 60% of slag, with constant w/c ratio of 0.33 and under water and air curing conditions. They used chemical activation and found that the maximum strength could be achieved about 63 MPa at 56 age days for 50% replacement level. Based on many investigations [8-14] on the effect of using cementitious materials in mortar, it was found that the effect of curing method and the volume level of cement replacement significantly influence the strength and durability.

In this experimental work, four mixes containing high volume cementitious materials as cement replacement have been used and one mix as a control. Mortar specimens were cured under four curing conditions after demoulding to find the effective curing condition for mortar containing high volume cementitious materials.

2. Experiment

2.1 Properties Material

2.1.1 Cement

The cement used in all mixes was ordinary Portland cement (OPC). The specific gravity of cement was about 3.14. The chemical compositions of OPC have been determined by ‘‘X-ray fluorescence spectrometry (XRF)” testing method. The compositions of OPC are given in Table 1.

Table 1 Chemical composition of OPC and BAMBOO ASH(% by mass)

Chemical Composition	OPC	BAMBOO 1	BAMBOO 2
SiO_2	20.14	39.86	36.44
CaO	60.82	12.72	12.72
Al_2O_3	3.89	17.10	17.10
MgO	3.10	6.79	6.79
Fe_2O_3	3.35	14.98	17.66
P_2O_5	0.064	0.20	0.271
MnO	0.14	0.18	0.18
K_2O	0.24	1.03	1.03
TiO_2	0.16	0.89	0.90
SO_3	2.25	0.58	0.75
SrO	0.02	0.06	0.06
LOI	2.33	0.70	4.70

*LOI = Loss on Ignition

1.1.1. BAMBOO I

Bamboo ash I is the most common source material for geopolymer because it is available in abundance throughout the world. It also contains amorphous alumina silica. The specific gravity of the bamboo ash used in the study is approximately 2.28, with its bulk density of 994 kg/m^3. The color of fly ash was whitish grey.

1.1.2. BAMBOO II

bamboo II, the most widely used supplementary cementitious material, is a byproduct, of the combustion of pulverized pure bamboo in power generating plants. It is available in abundance throughout the world. Fly Ash II was produced in Maros, South Sulawesi, was used. It is mainly contains amorphous alumina silica, iron, and calcium. The specific gravity of the bamboo ash used in the study is approximately 2.8. The color of bamboo ash was grey. The chemical characteristics of bamboo ash II are given in Table 1.

1.1.3. Aggregates

The fine aggregate used in the mixes was mining sands with specific gravity and fineness modulus (BS812: clause 21) of 2.65 and 2.72, respectively. The maximum grain size of sand was 4.75 mm.

1.1.4. Superplasticizer

In order to have appropriate consistency with low water to binder (W/B) ratio, superplasticizer (SP) was required. The specific gravity of SP used was approximately 1.195. It was dark brown in color, with a pH in the range of 6.0–9.0. The consumed content of SP in the mortar depends on the replacement level of cementitious material. For a flow of 140±10 mm, the SP used was 0.5-1% of total binder.

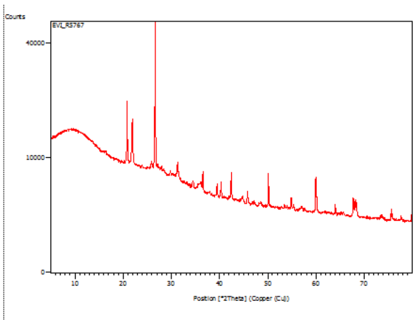
1.1.5. Water

The water used in all mixes was water in pipeline of the lab. It was assumed that the specific gravity of the used water was about 1.

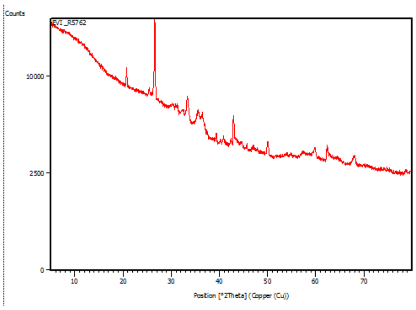
1.1.5.1. X-Ray Diffraction (XRD)

X-rays are electromagnetic waves, similar to light, but with a much shorter wave length (λ=0.2-200 A) [31]. Diffraction is a physical phenomenon that consists in electromagnetic waves avoiding of obstacles when obstacles have a size that compares to the wavelength [32]. So, X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The samples analyzed are OPC, BAMBOO 1 and BAMBOO II in powder form.

a)



b)



c)

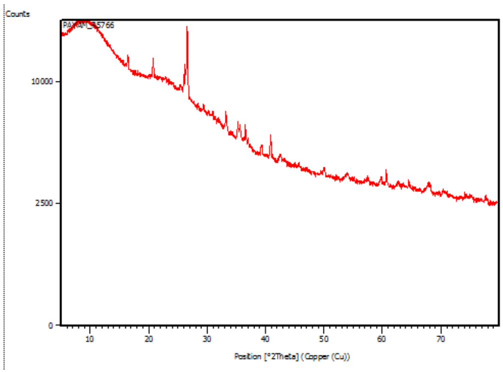


Fig. 5 XRD results for a) OPC, b) Bamboo Ash I and c) Bamboo Ash II

As seen in Fig. 5, XRD results appeared in the number of peaks. The peaks appeared corresponding to the crystallinity of materials. If the intensity of some peaks is high it indicates the abundance concentration of those crystalline planes [29, 30]. The narrow sharper peaks mean larger crystallite size or more crystallinity. The XRD pattern for bamboo 1 in Fig. 5b showed a diffuse band due to its amorphous and poor crystalline composition. If BA (Fig. 5c) absorbed water, the mixture will be dry while it increases workability. It is due to BA having higher amorphous structure than OPC (Fig. 5a). As displayed in Fig. 5, OPC has more peaks than BA which was dominated by the crystal structure. BA absolutely amorphous due to the wider sharper peaks was shown in Fig. 5d. It should be noted that micromolecular phase and reactivity level of OPC, BA1, and BA II classified as crystal and amorphous. Crystal has a regular and repeatedly structure of atom while amorphous has an irregular structure [29]. Amorphous structure can easily soluble in water due to weak bonds between molecules (flexible). Karim et al, [37] reported that generally, crystal structure has a strong reaction between compounds rather than the amorphous structure viewed from their bonding structure. However in the most cases, reactivity is primarily due to the subatomic properties of the compound [35, 37-39]. Therefore, OPC and BAMBOO ash will activated if be in crystal form, while reactivity of BA 1 and BA II when be in amorphous form as shown in Fig. 5. Generally, pozzolanic material contains crystalline and amorphous. It can be filler if not react with calcium hydroxide (CaOH) [38]. Crystalline has a coarse grain called crystal whereas amorphous in a finer granule likely similar to flour form. So, when react with water, materials in amorphous form is better than crystalline due to their fineness.

1.2. Mix proportions and mixing procedure

Table 2 represents the mix proportions for different mortars. In all mixes w/c ratio is 0.32. PC contains 100% ordinary Portland cement (OPC). While in the rest mixes, 50% of OPC was substituted by one or two types of cementitious materials. PG, BA 1, and BA II represent mortar containing 50% BAMBOO ash, respectively.

At first, sand were put in as a mixture and mixed for 5 minutes. After that the cement and supplementary cementitious material (SCMs) were added and mixing was done for 5–8 minutes. Later on, the calculated water was poured into the mix and the mixing continued for 2 minutes. Then, the superplasticizer was added and mixing continued for 2-3 minutes. Afterward, the flow test was performed and the specimens were moulded. The moulds were filled with fresh mortar and compacted with vibration table.

Table 2 Mix proportion of mortars (Kg/m^3)

Mix Code	Binder			Water	Sand	w/c	SP (%)	Flow
	Cement	BA I	BA II					
PC	550.0	0	0	213.40	1537.6	0.32	0.60	140±10 mm
BA I	275.0	275.0	0	213.40	1537.6	0.32	0.50	
BA II	275.0	0	275.0	213.40	1537.6	0.32	0.10	

Type of mixes	1 day without heating process
PC	5.21
BA1	2.95
BA II	1.33

1.3. Test for fresh mortar

In order to have appropriate consistency for each mortar, a flow table test according to ASTM C230/C230M-08 [23] was performed. The range of flow amounts were 140±10 mm. First, some mortar was put in the truncated brass cone in two layer sand each layer was compacted 10±5 times by a steel rod of 16 mm diameter till it solid. The cone was then lifted and the mortar was collapsed on the flow table. Following that, both the flow table and mortar were jolted 15 times in a period of 60 s. The jolting of the table allowed the mortar to spread out and the maximum spread to the two edges of the table was recorded. The average of both records was calculated as flow in mm.

2. Result and discussion

2.1. Compressive strength

The results obtained in the study for compressive strengths, based on heating time, are given in Table 3. The data inventory in this table examined two subjects. The compressive strengths obtained for different short time heat durations and also provided the result for 1 day test immediately after demoulding. As expected, substitution of OPC by cementitious materials up to 50% significantly reduced the 1-day compressive strength. The lowest reduction was observed in PG mix by a reduction about 38%. While, the great reduction was observed in mixes containing BA. The average reduction of these mixes was about 54%. It shows that contribution of BA (from 25%-50%) in high volume substitution level can significantly reduce the compressive strength of mortar. However, test results of early heating curing show that the reduction on the compressive strength can be compensated by using early hot water curing. Hot water curing for 2.5 h significantly improved the compressive strength of mortar containing 50% Bamboo ash. The 1-day compressive strength of the mix containing Bamboo ash 2 (BA II mix) after 2.5 h hot water curing was almost the same as control mortar under normal water curing.

Table 5 The 1-day compressive strength test results in normal and early hot-water curing condition

Among two mortars containing binary blended cement (BA 1 and BA II), the enhancement for 1-day compressive strength was for mortar containing 25% BA. Increasing the duration of hot water curing from 2.5 h to 5 h did not have any effect on the compressive strength gain. While, for all mortars containing binary blended cement, compressive strength improved of about 14-28%. This improvement was more significant for mixes containing 25% or 50% BA. The results indicated that early hot water curing is an effective method in order to gain 1-day strength for cement based materials. In general, it can be specified that early hot water curing is more effective to enhance the compressive strength if the sum of CaO content of the binder is more than SiO_2 content.

Tabel 3. The Compressive Strength Results

Mixes	**Compressive Strength (*f'c*) (MPa)**		
	1	**3**	**7**
PC Mortar	5.14 5.35 5.14	12.44 12.50 12.68	15.03 15.02 15.03
Average	**5.21**	**12.54**	**15.03**
MORTAR AB 25%	2.77 3.45 2.63	9.84 9.73 9.92	12.47 12.45 12.51
Average	**2.95**	**9.83**	**12.48**
MORTAR AB 50%	1.70 1.24 1.05	4.17 4.16 4.18	10.02 9.87 10.23
Average	**1.33**	**4.17**	**10.04**

Tabel 5. Compressive Strength Results

Mixes	**Compressive Strength (*f'c*) (MPa)**		
	1	**3**	**7**
MORTAR CNT	5.14 5.35 5.14	16.31 16.28 16.34	20.64 20.58 20.61
Average	**5.21**	**16.33**	**20.69**
MORTAR AB 25%	2.77 3.45 2.63	11.82 11.83 11.81	19.28 19.27 19.29
Average	**2.95**	**11.82**	**19.28**
MORTAR AB	1.70 1.24	4.12 4.11	9.63 9.65

50%	1.05	4.13	9.64
Average	**1.33**	**4.12**	**9.64**

Based on the results, it can be seen generally that at 3, 7 and 14 days strengths, for specimens cured in the water (HWC) the compressive strength is greater than the specimens cured under room temperature (HAC). This reality has proven for binary blended cement. Conversely, the aforementioned statement is reversed for binary blended cement containing BA II at the same ages. The strength of binary blended cement mortar containing BA 1 (25%) and cured under room temperature (HAC) was higher compared to the strength of specimens cured in water. It may be due to two reasons: first, as observed in Bamboo is a porous material. This porosity can observe the free water at the time of casting. This absorbed water may have a significant role for internal curing. This role of BA was already reported by other researchers [40-42]. They confirmed that BA particles are finest and porous appeared to be most effective in mitigating process. BA particles obviously best prepared to absorb a certain amount of water into its pores. Then, in the lack of available water, the absorbed water can be released to maintain hydration of cement (induced). The pores structure of BA which is induced called internal curing of mortar. Second, it was shown in the FTIR and XRD test that BA has high reactivity potential in the form of silica amorphous. In addition, it has high specific surface area. Therefore, mortar containing a combination of BA I and BA II gain better strength under HAC condition compared to HWC condition.

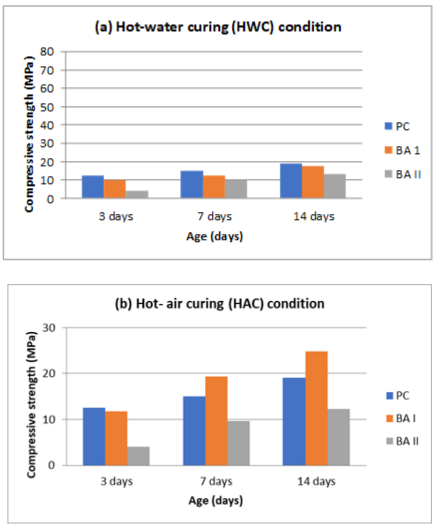


Fig. 9 The compressive strength result of mortar under heating process at early ages in HWC (a) and HAC (b) conditions

It can be seen generally that HAC condition showed the highest strength results compared with other three conditions at later ages. It was cleared that under WC condition, PC mortar gave lower strength than BA I mortar but shows higher strength than BA II mortars. It is related to the presence of crystalline structure from volume of bamboo ashwhich can improve strengths at later ages [17]. Generally, from the results obtained for HAC condition, it was observed that the strength of BA I mortars were higher than those of 50 percent of bamboo ash mortars in all later ages.

Overall, the strength comparison of five group mortars at the later ages showed that BA I mortars gave the highest strengths cured under HAC condition. The lowest strengths are related to BA II mortars almost in all curing conditions and PC mortar has medium strengths and improve steadily in all curing conditions. According to the results obtained in the study, it can be said that thermal activation with air cured (HAC) is one of the effective methods for the activation of OPC-cementitious materials.

3. Conclusion

In this study, the effect of curing condition on some properties of a mortar containing high volume cementitious materials such as bamboo ash were investigated. 50% of OPC was substituted by one or two types of these pozzolanic materials. Based on the experimental work, the following conclusions can be drawn:

1. The substitution of OPC by cementitious materials such as bamboo ash up to 50% significantly reduced the 1-day compressive strength in normal condition. Whereas, the short time early hot water curing can be specified as an effective method in order to gain 1-day strength for cement based materials. This heating method is more effective when 25% bamboo ash is used in the mixture.
2. Thermal activation then following air curing (HAC) is the effective way to produce a denser microstructure of mortar containing cementitious

materials and consequently to achieve the higher compressive strength with lower water absorption.

References

US Geological Survey. Cement statistics and information. In: Mineral Commodity Summaries. US Geological Survey. US Department of the interior. Reston. 2014. P. 44-46. http://minerals.usgs.gov/minerals/pubs/commodity/cement/index.html accessed March 9th, 2015.

Aldea CM, Young F, Wang K, Shah SP. Effects of curing conditions on properties of concrete using slag replacement. Cement and Concrete Research 2000;30(3):465–72.

Escalante-Garcia JI, Sharp JH. The microstructure and mechanicalproperties of blended cements hydrated at various temperatures. Cement and Concrete Research 2001;31(5):695–702.

Bagel L. Strength and pore structure of ternary blended cementmortars containing blast furnace slag and silica fume. Cement and Concrete Research1998;28(7):1011–20.

Dongxue L, Xinhua F, Xuequan W, Mingshu T. Durability study ofsteel slag cement. Cement and Concrete Research 1997;27(7):983–7.

Ekaputri JJ, Ishida T, Maekawa K. Autogeneous shrinkage of mortars made withdifferent types of sag cement. JCI annual convention, 1st ed. Japan: Saitama;2010.

Boubitsas D. Replacement of cement by limestone filler or ground granulatedblast furnace slag: the effect of chloride penetration in cement mortars. NordConcrete Research 2001;45(36):65–77.

Varga I, Castro J, Bentz D and Weiss J. Application of internal curing for mixtures containing high volumes of fly ash. Cement and Concrete Composites 2012;34:1001-1008.

Herrera AD, Juarez CA, Valdez P, Bentz DP. Evaluation of sustainable high volume fly ash concrete. Cement and Concrete Composite 2011;33:39–45.

Siddique R. Properties of self-compacting concrete containing Class F fly ash.Material Design 2011;32:1501–7.

Wongkeo W, Thongsanitgran P, Chaipanich A. Compressive strength and drying shrinkage of fly ash-bottom ash-silica fumemulti-blended cement mortars. Materials design 2012; 36: 655 – 662.

Agarwal SK. Pozzolanic activity of various siliceous materials. Cement and Concrete research 2006; 36: 1735 – 1739.

Ezziane K, Bougara A, Kadri A, Khelafi H, Kadri E. Compressive strength of mortar containing natural pozzolan under various curing temperature. Cement and concrete composites 20017; 29: 587 – 593.

Sajedi F, Razak HA. The effect of chemical activators on early strength of ordinary Portland cement-slag mortars. Construction and building materials 2010; 24: 1944-1951.

Stepehen OE. Role of heat curing in concrete durability. PhD thesis. Canada: University of Toronto; 2004.

Kim JK, Han SH, Chul SY. Effect of temperature and aging on the mechanical properties of concrete. Part I. Experimental results. Cement and concrete research 2002; 32: 1087 – 1094.

Sajedi F, Abdul Razak H. Effects of thermal and mechanical activation methods on compressive strength of ordinary Portland cement-slag mortar. Material design 2011; 32: 984 – 995.

Carino NJ. The maturity method: theory and application. JCCA 1984; 6: 61-73.

Sajedi F, Abdul Razak H. Comparison of different methods for activation of ordinary Portland cement-slag mortars. Construction and building material 2011; 25: 30 – 38.

Sivakumar G, Mohanraj K, Barathan S. dielectric study on fly ash blended cement. E-Journal of chemistry 2009; 6 (1): 231-236.

ASTM C109/C109M-08. Standard test method for compressive strength ofhydraulic cement mortars (using 2-in. or [50-mm] cube specimens).

ASTM C989-09a. Standard specification for slag cement for use in concrete andmortars.

ASTM C230/C230M-08. Standard specifications for flow table for use in tests ofhydraulic cement.

Hu C. Microstructure and mechanical properties of fly ash blended cement pastes. Construstion and building materials 2014; 73: 618 – 625.