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Research Paper

The Effect Of Thermal Activation Time and Type Of Fly Ash On The Compressive Strength Of High Volume Fly Ash-Bamboo Mortar

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ABSTRACT

A growing number of concrete productions per year will lead to increase manufactured cement significantly. Bamboo is one of the main materials from agriculture, it has many function particularly in the field of agriculture. This research is including waste materials origin from bamboo. The methodology used are curing in a hot water after 24 h and curing at the room temperature. The compressive strength is equal to the mortar containing 100% cement. 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.

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. A growing number of concrete productions per year will lead to increase manufactured cement significantly. Since, one of major contributor to CO2 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 . 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. 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. The kind of alternative material that is used often depends on the availability and on the field of application. However the common alternative materials used include FA. The utilization of mineral admixtures improved the compressive strength, pore structure, and permeability of the mortars and concretes with time. This

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is because the total porosity decrease with increasing hydration time.

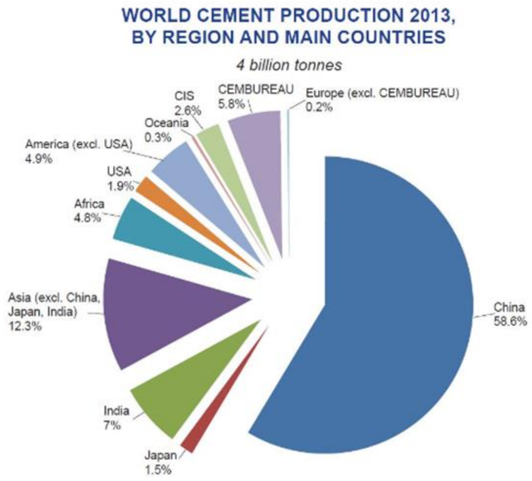


Fig. 1. The cement production around the world in 2013

There are many reports 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. 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 and Boubitsas 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. In 2001, Boubitsas 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. The percentage of low and moderate for cement replacement levels are 5% to 40% by mass, respectively. In addition, Agarwal 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, 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. Varga et al, 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., 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 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 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.

GGBFS, FA, and RHA are a latent hydraulic binder. It must be activated to react and provide the desirable mechanical properties using several methods. One of these activation methods is the thermal method. The heat curing on cementitious systems and heat treatment of mortar have become a regulated practice in the precast industry. Presently, the most developing countries have developed specifications for the regulation of heat curing for precast concrete. Previous investigations showed that hot water curing method improves strength at the early ages. However, at a later age, a loss of ultimate strength may be occurred in specimens. This is due to the important numbers of formed hydrates have no time to arrange suitably and this causes a loss of ultimate strength. This behaviour has been called the crossover effect. For ordinary Portland cement (OPC), it appears that the ultimate strength decreases with curing temperature linearly.

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. Materials and method

2.1 Properties of materials

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, GGBFS, FA and RHA (%BY mass)

Chemical Composition	OPC	FA1	FA2
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	0,18819
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

2.1.2 Fly Ash I

Fly 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 fly ash used in the study is approximately 2.28, with its bulk density of 994 kg/m3. The color of fly ash was whitish grey.

2.1.3 Fly Ash II

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

2.1.4 Agregates

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.

2.1.5 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.

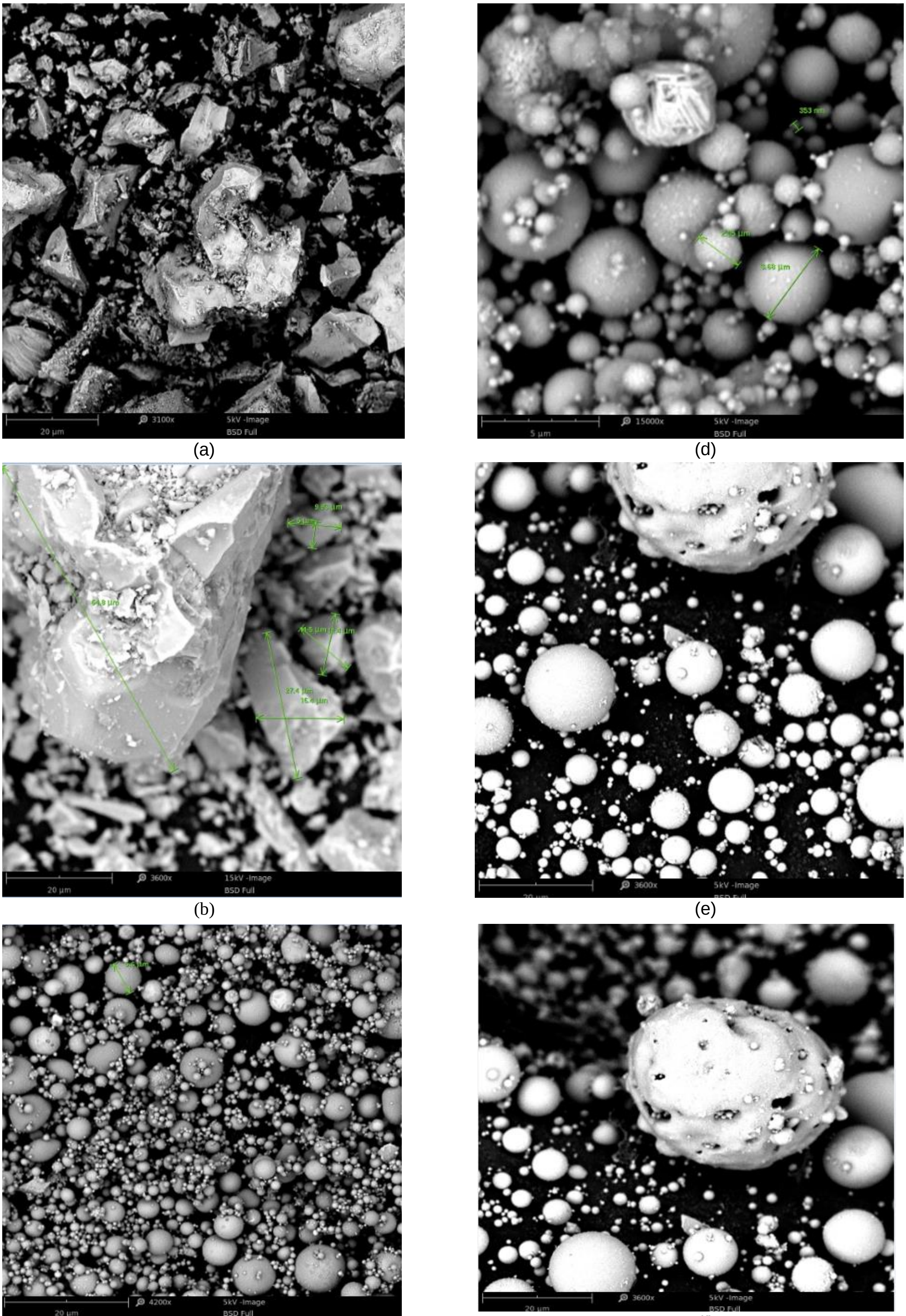
2.1.6 Superplasticizer

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.

2.1.7 Scan Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FT-IR) and X-Ray Diffractometry (XRD) for cementitious materials in powder form

2.1.7.1 Scan Electron Microscopy (SEM)

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interaction sreveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. The SEM is also capable of performing analyses of selected point locations on the sample.



(a) (d) (b) (e) (c) (f)

Fig. 3. SEM result for a, b) OPC; c, d) FAI; e, f) FAII

SEM micrographs of OPC and SCMs samples are shown in **Fig. 3.** The samples used are in powder form. They are OPC, GGBFS, FA and RHA. It can be seen that OPC (**Fig. 3a**) and GGBFS (**Fig. 3c**) have a similar shape resembling an irregular prism. Furthermore, **Fig. 3e** shows that all FA grains are in the spherules shape. Due to the spherules shapes of fly ash, the use of this SCM will increase the workability of mortar/concrete. While SEM of RHA (**Fig. 3e**), display prism elements with many porous on it. Due to these porosities in RHA and consequently higher specific surface area, it can be used as SCM in low or moderate volume. The use of high volume RHA causes mixture be dried. However, when it is used by other type of SCMs, the workability of mixture could be good or satisfactory. Therefore, RHA combine together with FA were used in this study..

2.2 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, PF, PGF and PRF represent mortar containing 50% GGBFS; 50% FA; 25% GGBFS with 25% FA and 25% RHA with 25% FA, 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	FA I	FA II					
PC	550.0	0	0	213.4	1537.6	0.32	0,041667	140±10 mm
PF I	275.0	275.0	0	213.4	1537.6	0.32	00.50	
PF II	275.0	0	275.0	213.4	1537.6	0.32	00.10	

2.3 Test for fresh mortar

In order to have appropriate consistency for each mortar, a flow table test according to ASTM C230/C230M-08 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.

2.4 Curing conditions

The specimens were demoulded 24 h after casting. After demoulding, the specimens were divided to five groups to consider four conditions on properties of mortars containing high volume cementitious materials. Some specimens directly cured in normal water (WC) with 23 ± 3ºC temperature and also cured in air (AC) under room temperature of 27 ± 4ºC with 70 ± 10% relative humidity. The rest of specimens were heated in water at 60ºC for 24 h first, and then they were divided into two groups to be cured in air (HAC) under room temperature as well as water curing (HWC) until the test day. In addition, to investigate early hot water curing on the early strength of mortar, 3 cube specimens were heated for 2½ h and also 5 h. In this condition, the compressive strength at 1 day age conducted.

Hardened mortars can reach their maximum strength within several hours through elevated curing temperature. However, the ultimate strength of hardened mortars and concretes has been shown to decrease with curing temperature. It was found that by increasing the curing temperature up to 60ºC and the heating time to 24 h causes a continuous increase in compressive strength. Therefore, this temperature was selected in this study.

2.5 Test for hardened mortar

2.5.1 Compressive and flexural strength

All of the specimens within four conditions were cured until they were used for compressive strength tests at 3, 7, 14, 28, 56 and 90 days age. The compressive strength measurements were carried out using an ELE testing machine press with a capacity of 2000 kN and a loading rate of 0.k kN/s. Compressive tests were done according to BS EN 12390-3-09.

While, for flexural strength test conducted at 7 and 28 age days two curing conditions of HWC and HAC. For flexural strength test, the specimens were put the specimen above 2 equal pedestals then saddled with a load evenly located in the middle span, as well as the addition of the load gradually until it reaches the fracture and obtain the maximum load value (P_{maks}) was shown at **Fig. 6.**

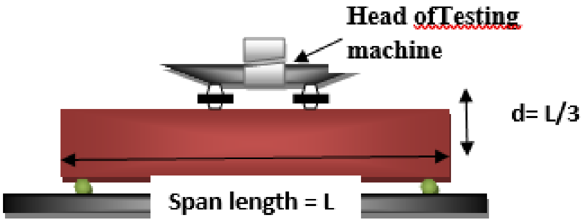


Fig. 6. The illustrated test for flexural strength of mortar

2.5.2 Water absorption

Water absorption test conducted at 56 days age. Water absorption was determined using a mortar cube of 50 mm × 50 mm × 50 mm. In this regard, cube specimens were dried in oven for 24±2 h until constant weight. Then they were weighted in air immediately (*Wa*) after removing from oven and also after immersion periods of 30 min and 72 h. Thus, water absorption of the specimen was calculated as 100 × (Wa – Wd)/Wd.

2.5.3 Porosity

The porosity test for hardened mortar conducted when the mortar reach 56 days age. Porosity tests carried out on cubical samples with the size of 50x50x50 mm. The purpose of this test is to determine the percentage of pores of the concrete/mortar to the volume of solid concrete/mortar.

As it is known that the compressive strength of mortar/concrete is influenced by the porosity. More porous present in the mortar specimen, the lower compressive strength produced. The porosity test set up was shown in **Fig. 7.** The steps of the test are as follows:

1. Samples of each condition at 56 days removed from the curing tubs and aerated.
2. Prepare the specimens and then put in the oven at 100±5°C for 24 hours.
3. The specimens were removed from the oven and aerated at room temperature (25°C) and then weighed. The weight of the mortar obtained was oven dry condition (C).
4. The specimens were put in a dessicator to vacuum process using a vacuum pump as mentioned in **Fig. 7.** The vacuum process of the specimen as long as 24±2 hours. After that, the specimen flowing with water until all sides of the specimens completely submerged in water. Immersion process of the specimens also in vacuum conditions and performed for 24 hours. Then, weighed and obtained the weight in water (A).
5. The specimens were removed from the water and wipe the surface to get a SSD condition then the samples were weighed. The weight of the mortar conditions of SSD obtained after immersion (B).

Fig. 7. Porosity test using SMART-CL vacuum dessicator with moisture trap

From the above test results, the porosity value was calculated based on the following formula:

$$\text{Porosity} = \left(\frac{B-C}{B-A}\right) x\ 100\% \quad [1]$$

Where, A is the weight of the specimens in water, B is the weight of the specimens in SSD condition and C is the weight of the specimens in oven dry condition.

3. Results and discussions

3.1 Compressive strength

The compressive strength results were divided by four sections, as follows:

3.1.1 The compressive strength in normal and under early hot-water curing conditions

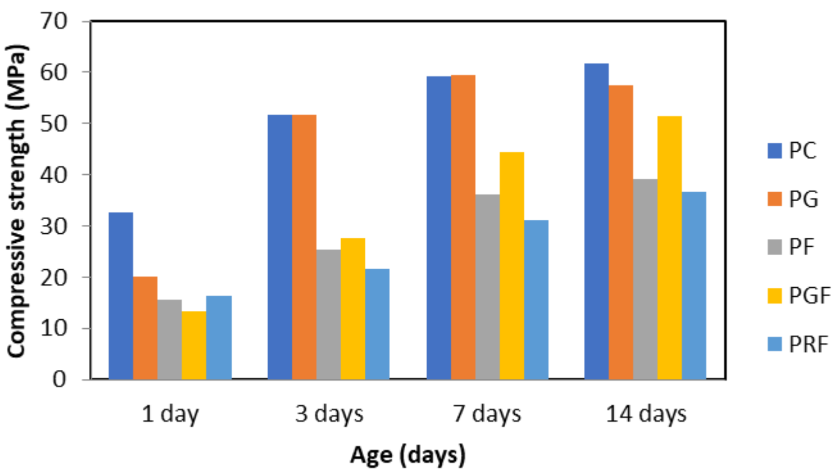
The results obtained in the study for compressive strengths, based on heating time, are given in Table 3. The data inventory in this table examined two subjects. The compressive strengths obtained for different short time heat durations and also provided the result for 1 day test immediately after demoulding. 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 FA. The average reduction of these mixes was about 54%. It shows that contribution of FA (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% GGBFS. The 1-day compressive strength of the mix containing GGBFS (PG 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

Type of mixes	1 day without heating process	2.5 hour in hot water	5 hour in hot water
PC	32.53	41.10	41.60
PF5	14.02	17.04	22.05
PF	15.57	17.10	19.50
PF24	12.08	15.04	17.02

Among two mortars containing ternary blended cement (PGF and PRF), the enhancement for 1-day compressive strength was for mortar containing 25% GGBFS. 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% GGBFS. 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.



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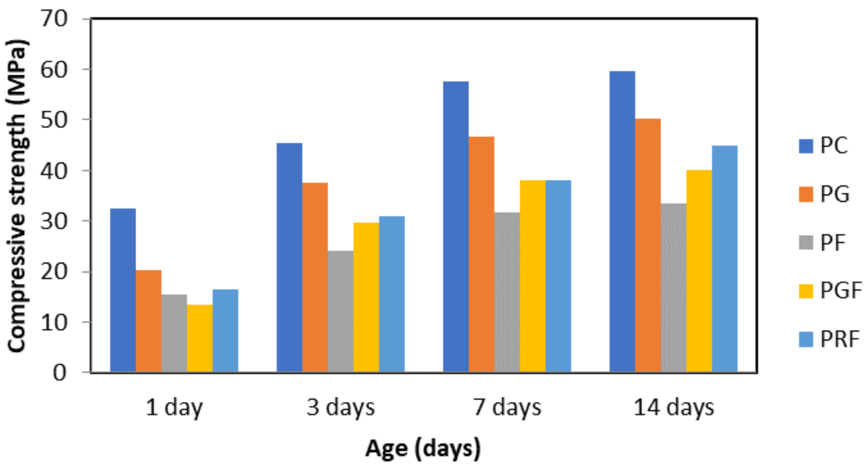


(b)

Fig. 8. The compressive strength of mortar without heating process at early ages for WC (a) and AC (b) conditions

Table 4. Compressive strength results in different curing

Type of mixes	3 days	7 days	14 days	28 days	56 days	90 days
Water curing conditions (WC)						
PC	51.67	59.30.00	61.80	66.05.00	59.40.00	68.55.00
PF5	31.00.00	36.05.00	42.04.00	49.00.00	56.03.00	60.06.00
PFS	25.26.00	36.08.00	39.06.00	43.90	55.89	57.72
PF24	22.07	30.08.00	34.03.00	40.08.00	49.00.00	54.09.00
Air curing conditions (AC)						
PC	45.36.00	57.67	59.72	63.26.00	56.40.00	59.93
PF5	28.07.00	35.08.00	39.02.00	44.05.00	53.71	58.01.00
PFS	24.05.00	31.70	33.50.00	38.76	46.20.00	50.11.00
PF24	23.07	28.01.00	36.01.00	40.00.00	42.04.00	50.03.00
Hot – water curing conditions(HWC)						
PC	50.50.00	52.95	54.90	62.60	61.70	68.73
PF5	32.00.00	37.06.00	43.04.00	46.03.00	55.07.00	59.06.00
PFS	37.85	40.80	41.77	48.85	56.20.00	58.12.00
PF24	34.07.00	39.05.00	44.08.00	48.01.00	51.04.00	55.04.00
Hot – air curing conditions (HAC)						
PC	53.40.00	61.30.00	65.10.00	66.90	63.80	70.90
PF5	32.05.00	37.07.00	44.06.00	52.01.00	59.03.00	61.20.00
PFS	42.20.00	48.40.00	50.60	54.20.00	56.60	60.66
PF24	40.00.00	41.07.00	49.04.00	54.06.00	55.08.00	58.02.00

3.1.2 The compressive strength results at early ages for WC and AC without heating process

Fig. 8. shows the compressive strengths development of all mortars containing 50% of pozzolan. Based on the results, it can be seen generally that at 3, 7 and 14 days strengths, for specimens cured in the water (WC) the compressive strength is greater than the specimens cured under room temperature (AC).

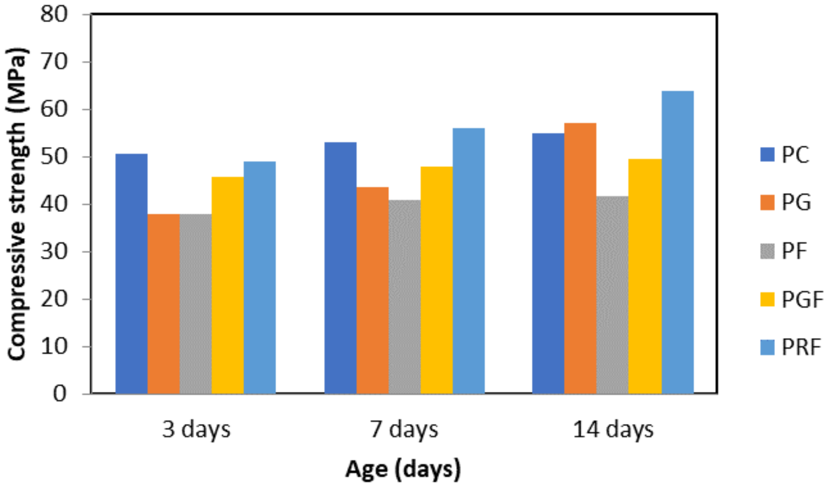
This reality has proven for binary blended cement. Conversely, the aforementioned statement is reversed for ternary blended cement containing RHA at the same ages. The strength of ternary blended cement mortar containing RHA and cured under room temperature (AC) was higher compared to the strength of specimens cured in water. It may be due to two reasons: first, as observed in the **Fig. 3.** that RHA 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 RHA was already reported by other researchers [40-42]. They confirmed that RHA particles are finest and porous appeared to be most effective in mitigating process. RHA 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 At 3 days age, compared to PC, the results revealed that PGF and PRF showed the lower strength in the decrease under WC about 15% and 33%, respectively, while in AC condition about 9% and 4%, respectively. The greater incremental strength was observed in mixes containing GGBFS. While, the highest strength loss was found in PF mixes by a total reduction about 23% and 26% for WC and AC, respectively. This fact shows that the type of binder plays a major role in strength improvement of the mortars in different curing conditions.

3.1.3 The compressive strength results at early ages for WC and AC without heating process

Variations of compressive strength for the specimens cured in HWC and HAC conditions are shown in **Fig. 9.** From this figure, it can be seen that in the most cases, the strengths of mortars cured in HAC are higher than those of mortars cured in HWC in all early ages. The results revealed that with the use of heating process, the compressive strength of PC mortar under room temperature (HAC) increased by on average 14% compared to PC mortar cured in water (HWC). In addition, when 50% GGBFS is used in mortar (PG), the strength increased by on average 12% compared to PC mortar under HAC condition at all early ages. Reversely, when PG mortars cured in HWC condition obtained lower strength by 24% and 18% compared to PC mortars for 3 days and 7 days, respectively. It could generally be said that whenever PG mortars are heated, it is prefer to cure under HAC condition than cured in water (HWC).

Meanwhile, the strength rate of PF and PGF compared to PC at all early ages, for both in HWC and HAC conditions, decreased by 24% and 10%, respectively. It was reported that the appearances of hydration of cement (induced). The pores structure of RHA which is induced called internal curing of mortar. Second, it was shown in the FTIR and XRD test that RHA has high reactivity potential in the form of silica amorphous. In addition, it has high specific surface area. Therefore, mortar containing a combination of RHA and FA gain better strength under AC condition compared to WC condition.
the strength was slowed in the early ages and continuously for a long curing period by adding FA for more than 30%. It is due to the chemical reaction in mortar, in terms of hydration process. The hydration process result indicates that chemical composition such as SiO_2 and CaO (in the vicinity of the interface) is one of the major factors for the increase in bond strength. However, Chindaprasirt and Rukzon [28] reported that FA might become effective for strength increase by addition of other pozzolanic materials which participate with some reactions to gain the strength. Therefore, as mentioned from XRD results (section 2.1.8.3), the other cementitious material which has a high reactivity similar to FA in silica amorphous form is RHA. Other case for mortar containing RHA with FA (PRF) compared to PC at 3 days, the strength decreased by 4% and 6% in HWC and HAC condition, respectively. However, this strength is increased by 6% and 16% at 7 and 14 days age, respectively for HWC condition.

Surprisingly, PRF mortar obtained the equivalent compressive strength at 14 days as much as 65 MPa in HAC condition. This results show that there is continuity in the hydration progress of PRF mortar from 7 days to 14 days, while the whole latent potential of PRF mortar released during early ages due to the heat effect. It can be said that by using combination of RHA with FA as partial substitute cement, several benefits provided such as reduced materials costs due to cement savings and environmentally friendly related to the utilization of waste materials as well as reduced CO_2 emissions from cement exploitation. As conclusion, it seems that whenever mortars cured under room temperature after heating (HAC), the strengths increase with the curing duration. Then, the fact shows that a proper combination of cementitious materials in binder plays a main role in the strength improvement of mortars.



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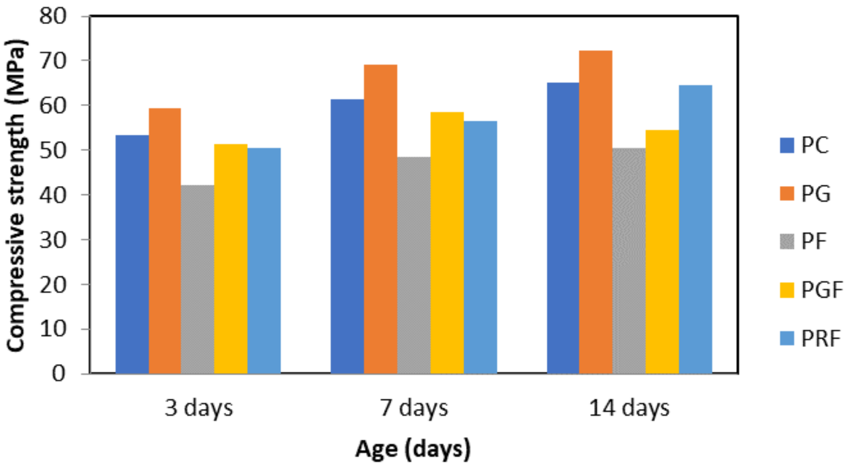


(b)

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

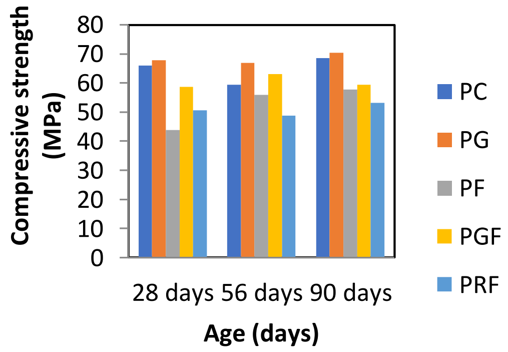
3.1.4 The compressive strength of mortars for all conditions at later ages

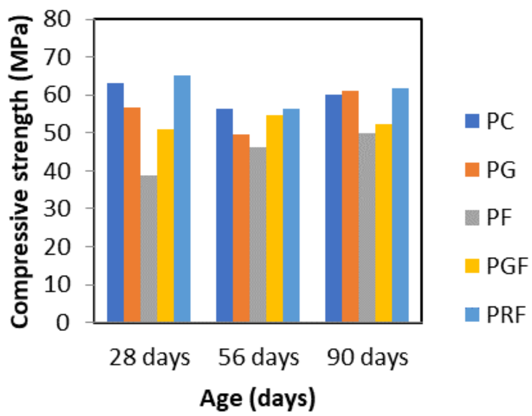
The compressive strength of five group mortars in different curing conditions continuously investigated at 28, 56 and 90 days age. The difference between curing conditions with and without heating process described clearly using column comparison as shown in **Fig. 10.** It can be seen generally that 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 PG mortar but shows higher strength than PF, PGF and PRF mortars. It is related to the presence of crystalline structure from GGBFS which can improve strengths at later ages. Generally, from the results obtained for AC condition, it was observed that the strength of PRF mortars were higher than those of PC, PG, PF and PGF mortars in all later ages. The results revealed that compared to PRF mortar, PC mortar and PG mortar under AC condition showed strength loss about on average 4% and 8%, respectively. Otherwise, PC mortar shows higher strength when compared to PGF mortar with incremental on average about 23% at all later ages. It should be noted that for the specimens cured at room temperature, the maximum relative humidity was 85% and air temperature of 27±3^{o}C whereas for the specimens cured in water is 100% with temperature by on average 23^{o}C. High relative humidity and air temperature may be the reasons for strength gain for some mortars under AC condition and also for the most mortars under HAC condition.

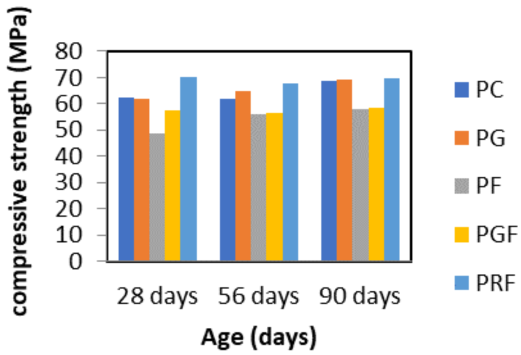
In two curing conditions with heating process, it is seen that the strength results of mortars cured in HWC is lower than HAC. Otherwise, for PGF mortar, the strengths were improved at all ages in water curing condition with or without heating process. As reported before, the OPC and GGBFS make mortar become more sensitive to air curing condition (AC). This fact can be attributed to high consistency of GGBFS nearby water. Whereas PRF mortar gain better strength at later ages if curing under room temperature than cured in water with or without heating process. This shows that the physical and chemical properties of RHA and FA combine with OPC more reactive when cured under room temperature. However, this also affected from high volume replacement level of cementitious materials. The encouraging results obtained were associated to the synergy between the ashes used [16]. Karim et al, reported that generally, reactivity is favoured by increasing fineness of the pozzolanic materials. The finest particles tend to concentrate near the interface between aggregate and cement matrix. The finest particle size leading to reduced porosity and enhanced internal bonding capacity of mortar at the same time. Chemical and physical properties such as fineness, active alumina and glass content are the main factors determining the pozzolanic activity and strength contribution of FA and RHA. Reactivity of RHA is attributed to its high content of amorphous silica, and to its very large surface area governed by the porous structure of the particles as shown in XRD and SEM results (section 2.1.8). RHA have the highest SiO_2 content but when mix with OPC in high volume, it will dry. At the stage of hydration process, the fly ash performed faster than GGBFS. It is due to the fineness particle and containing silica amorphous. So that, RHA combine with fly ash and produced the better flow and good workability. The combination of OPC, RHA and FA to be composite binder exhibit as the best mix compare to all combinations. It is due to the chemical and physical properties of these cementitious materials.

Overall, the strength comparison of five group mortars at the later ages showed that PRF mortars gave the highest strengths cured under HAC condition. The lowest strengths are related to PF mortars almost in all curing conditions and PG 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.

Based on curing conditions criteria, the strength of the specimens cured in air at room temperature after heat process (HAC) is the highest. The second level of strength is attributed to the specimens cured in water after the heating process (HWC). The third level is for those cured in water without the use of heating (WC) and the last is attributed to the specimens cured in air under room temperature without the use of heat process (AC). This result also shows that the thermal technique like HAC is a feasible and efficient method for the activation of ordinary Portland cement with high volume cementitious materials in mortars and concretes without the use of water to cure the specimens after heating process.







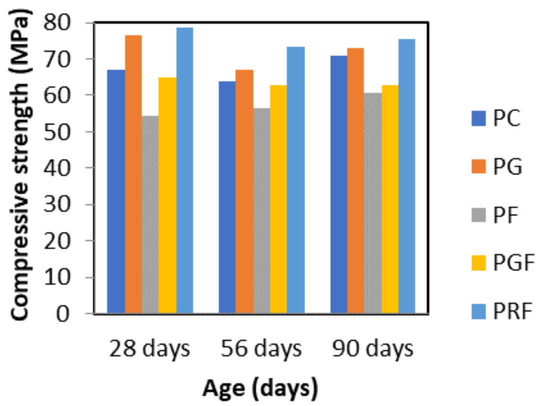


Fig. 10. The compressive strength result of mortars at later ages for WC (a), AC (b), HWC (c) and HAC (d) conditions

4. Conclusions

In this study, the effect of curing condition on some properties of a mortar containing high volume cementitious materials such as GGBFS, FA and RHA were investigated. 50% of OPC was substituted by one or two types of these pozzolanic materials. The specimens were cured in 4 conditions of WC, AC, HWC and HAC after demoulding. For these conditions, specimens were tested for 1 day immediately after demoulding and also after short time hot water curing (with a constant temperature of 60^{o}C) of 2.5 h and 5 h. In addition, the cube specimens were tested from 3 to 90 days age for all curing conditions. The flexural strength test conducted at 7 and 28 days in two curing conditions of HAC and HWC. Furthermore, the water absorption and porosity test were conducted at 56 days age of cube specimens. Based on the experimental work, the following conclusions can be drawn:

1. The substitution of OPC by cementitious materials such as FA, GGBFS and RHA 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 GGBFS is used in the mixture.
2. Generally, the compressive strength of OPC-cementitious materials cured in WC is greater than cured in AC condition at early ages. The greater incremental strength was observed in mortar containing GGBFS (PG), both in WC and AC conditions. PG and PC mortars showed similarity effect in order to gain the strength at early ages when cured in WC condition.
3. The compressive strength of OPC-cementitious materials cured in HAC are higher than those of mortar cured in HWC in all early ages.
4. Mortar containing cementitious materials cured under HAC obtained the highest compressive strength results compared to the other three curing conditions at the later ages. It was prove that the thermal technique (heat) like HAC is a feasible and efficient method for the activation of ordinary Portland cement with high volume cementitious materials in mortars and concretes. Therefore, it will reduce the exploitation of water usage and save energy as well.
5. From the results at the later ages, it is found that PRF mortars gave the highest compressive strength cured under HAC condition. While, the lowest strength are related to PF mortars in all curing conditions. Therefore, the fact shows that the type and combination of binder plays a major role in strength improvement of the mortars in different curing conditions.
6. The highest flexural strength is attributed to PRF mortar as 18 MPa at 28 days under HAC condition.

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.

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