A Study of Mechanical Performance of Supplementary Cementitious Material using Hot Water Curing

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Abstract. This study aims to investigate mechanical properties of supplementary cementitious material (SCM) using different curing condition. The utilization of huge number of agricultural waste material due to amount type has been disposed-off and being hazardous to the environment. This problem lies into reuse and renew those wastes to be useful materials. The combination of industrial and agricultural waste materials were used up to 50% in order to replace the use of cement. The result showed that using different curing step could be an effective way to produce high mechanical performance of mortars using supplementary cementitious materials.

1. Introduction

High priority has been given to protect and preserve environment from abundant non-renewable waste materials which is hazardous if not being disposed off safely. The total wastes accumulated are not valuable and will cause pollution when disposed off for a long time. Other priority was also intended to reduce the use of a huge amount of cement as a binder in construction industry.

Malhotra (2000) stated that the rate of the world’s population will increase explosively from 1.5 billion to 9 billion by 2050. It will result in an increased demand for energy, housing, food and particularly the demand for concrete. The total of concrete production is forecasted to grow up to about 18 billion tons annually by 2050 (Malhotra, 2000). Unfortunately, a huge amount of concrete produced conversely to its benefits. Arising in the demand of concrete will lead to the needs for cement as a main binder of concrete production.

About 2.5% of the total emissions across the globe is the result from Portland cement manufacturing which causes a great concern to the environmental sectors (Noorvand et al., 2013). At the same time, the type and amount of waste products increases with the growth in population. These wastes remain in the environment for a longer duration since they are unused. If those waste materials are not deposited safely, they may be hazardous. The solution to this environmental crisis lies in the recycling of waste materials to be partial replacement of Portland cement in the construction industry. To minimize the exploitation of Portland cement, the use of waste and by-product materials in high
volume as cement replacement is being focused in this study.

2. Experimental Procedure

The experiment start with preparing materials consists of raw materials and supplementary cementitious materials (SCM). Some SCMs were used are coming from agricultural namely rice husk ash, and palm oil ash. The raw materials used are ordinary Portland cement (OPC), fine aggregate, and water. The characteristics of materials were tested using Brunauer-Emmett-Teller (BET), X-ray fluorescence spectrometry (XRF), and Scanning Electron Microscopy (SEM).

The mortars were prepared in ten mixture proportion. The testing on mortar properties were divided into fresh mortar and hardened mortar. The test for fresh mortar was workability using flow table test. Then, the mortar mixes were cured under four curing conditions, consist of water curing (WC), air curing (AC), hot water curing (HWC) and hot air curing (HAC). While, the mechanical properties of hardened mortar were tested using compressive strength test and flexural strength test. The physical properties of hardened mortar were tested using water absorption test and porosity test.

2.1 Materials

Raw Materials used are Ordinary Portland Cement (OPC), Fine Aggregate (Mining Sand), Water (Distilled Water), Supplementary Cementitious Materials (SCM) used are GGBFS, RHA, POFA, and FA.

2.2 Equipments

XRF Spectrometer for XRF test, SEM-EDX type JEOL JSM-6360 LA for SEM test, BET sorption analyzer NOVA 2000 for BET test.

2.3 Mixing Procedures

Mixing all raw materials, casting and demolded them based on specified durations. The specimens were demoulded 24 h after casting. Then, the specimens were divided into five types of curing condition as shown in the Table 1. Five types of curing conditions are normal curing, water curing (WC), air curing (AC), hot air curing (HAC), and hot water curing (HWC).

| No | Type of Curing                      | Specimen |
|----|-------------------------------------|----------|
| 1  | Normal Condition                    | 3 cubes  |
|    | (The specimen directly tested after demoulded) |          |
| 2  | Water Curing (WC)                   | 24 cubes |
|    | (with 23 ±3°C temperature)          |          |
| 3  | Air Curing (AC)                     | 24 cubes |
|    | (under room temperature of 27 ±4°C with 70 ±10% relative humidity) |          |
4. Hot Air Curing (HAC),

The specimens were heating in hot water of 60°C temperature for 24 hour and then the specimens were moved to the place under room temperature of 27 ±4°C with 70 ±10% relative humidity.

5. Hot Water Curing (HWC)

3. Result and Discussion

The effect of hot water curing on the mechanical properties of ternary blended cement of cementitious mortar was investigated. An evaluation was conducted to determine the effect of using thermal process and different curing conditions as a cost-reducing in mortar.

The results of ternary blended cement mortars in different curing condition at early age can be seen in Figure 1 and Figure 2.

![Figure 1. The compressive strength result of mortar in a) WC & b) AC conditions](image-url)

The compressive strength of PGFII mixes using initial heating process gained the strength of 44% and 3% at 3 days and 7 days, respectively, compared to PGFII without heating process. Reversely, PGF II in HWC condition decreased about 17% at 14 days compared to WC condition. Based on the results, it can be seen generally that at 3 and 7 days strengths, for specimens cured in the HWC condition, the compressive strength is higher than the specimens cured without heating process (WC). Contrarily, the strength of PGFII mixes were cured in WC condition at 14 days show better performance than cured in HWC condition for about 17%. The delayed strength gain between 3 days to 7 days due to...
retardation clusters consist in FA under heating process. Other than that, mortar containing FA sets faster in WC condition, so that the strength at 7 days to 14 days increase much higher than in HWC conditions.

Through hot air conditions, secondary mix of GGBFS and fly ash shows higher at 4 times early ages. As detail, the compressive strength of PGFII cured under room temperature without heating process decreases for about 50%, 30% and 25% at 3 days, 7 days and 14 days, respectively. It can be seen that particularly under room temperature, ternary blended cement consist of 25% GGBFS and 25% FA will show better performance using initial heating process compared to PGFII mixes in AC conditions. The initial thermal process at 60°C for 24 h has an adverse effect on inner and outer microstructure of hydration product particularly in the case of calcium silicate hydration consists of fly ashes particles. Meanwhile, initial heating process will bring benefit effects on hydration product and the strength performance of mortar when after heating process followed by cured under room temperature, particularly for the mortars containing fly ash.

![Graph](c) Hot-water curing (HWC) condition

![Graph](d) Hot-air curing (HAC) condition

**Figure 2. The Mechanical Performance of Mortar Using Hot Air Curing and Hot Water Curing Method.**

The mortars containing 25% of palm oil ash compared to PPR mix show the decreased results. The strength obtained decreased by 14%, 18% and 35% for 3 days, 7 days and 14 days, respectively. Besides, the strength of mortar containing palm oil ash using thermal method increased on average of
25% and 21%, respectively. The specimens were cured using hot water will vary based on the content of waste materials inside. It can be seen that in the cases of the combination using palm oil ash and fly ash or PPF, the strengths obtained are much higher in all early ages. The results revealed that with the use of heating process, the compressive strength of PPF mortar under room temperature (HAC) increased by on average 30% compared to PPF mortar cured in water (AC). The results obtained from PPR mortars were cured in AC decreased by 32%, 27% and 5% compared to PPR mortar cured in HAC condition at 3 days, 7 days and 14 days, respectively. This trends show that at early ages, ternary blended cement consists of 25% POFA and 25% RHA is suitable to cure using hot water.

In addition, when 50% GGBFS and 25% FA are used in mortar (PGF II), the strength decreased by on average 20% compared to PPF mortar under HAC condition at all early ages. Reversely, when PGF II mortars cured in HWC condition obtained lower strength by 14% and 23% compared to PGF II mortars in HAC condition for 7 days and 14 days, respectively. The strength of ternary blended cement mortar containing low volume OPC (PGFII) cured under room temperature after heating process (HAC) was higher compared to the strength of specimens cured in water after initial thermal process (HWC). It may be due to the low portion of OPC used but the volume of GGBFS-FA is higher (up to 75%). As observed in the Chapter 3 that FA is fineness and has a high surface area, so it needs water to react well. Furthermore, the actual reactivity of GGBFS depends on its composition, glassy content as well as similarity behavior to fly ash (Thomas et al, 1999; Roy, 1987). It could generally be said that whenever PGF II mortars are heated, it is prefer to cure under HAC condition than cured in water (HWC).

As conclusion, the combination of OPC and 25% POFA with 25% RHA (PPR) and PPF are suitable to cure in water after heating process (HWC) at early ages. Meanwhile, the control mortar or PC mix is better cure in water, due to the chemical reaction of pure 100% Portland cement going faster at the early ages. Continuously, POFA when used in a high volume, it was shown in the trial mix that the result failed (dry/bad flow).

High consistency of slag or ground granulated blast furnace slag obtained if nearby water. Meanwhile, at the stage of hydration process, it performed slower than fly ash. It is due to the fineness particle and containing silica amorphous. Therefore, half percent of GGBFS should be combining with fly ash. The combination of GGBFS and fly ash produced the better flow and good workability when cured in water. The strength gained also caused by a high relative humidity and air temperature.

The lowest strengths are related to PPR 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. Otherwise, control mortar mixes produced the better performance instead of mechanical properties of mortar itself. It can be seen generally that the highest strength results is attributed for mortar using initial hot water curing (HAC) condition at later ages.

4. Conclusion
In this study, ten types of mixture were analyzed to determine the optimum curing conditions in order to gain the better properties of mortar containing high volume cementitious materials. Generally, the compressive strength of mortar containing high volume cementitious material which was cured in WC is greater than cured in AC condition at early ages. The greater incremental strength was observed in PG mortar, 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. Whereas, the compressive strength of mortar containing high volume cementitious materials which was cured in HAC are higher than those of mortar cured in HWC. It is found that PRF mortar gave the highest compressive strength cured under HAC condition. While, the lowest strength is PF mortar in all curing conditions. the strength comparison of two group mortars containing POFA (PPR, and PPF) at the later ages showed that PPF
mortars gave the highest strengths cured under HAC condition. It could generally be said that whenever PGF II mortars are heated, it is prefer to cure under HAC condition than cured in water (HWC).

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