EFFECT OF FLY ASH ON PHYSICAL AND MECHANICAL PROPERTIES OF MORTAR

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Abstract - This research investigates the physical and mechanical properties of mortar incorporating fly ash (FA), which is by-product of Duyen Hai thermal power plant. Six mixtures of mortar are produced with FA at level of 0%, 10%, 20%, 30%, 40%, and 50% (by volume) as cement replacement and at water-to-binder (W/B) of 0.5. The flow, density, compressive strength, flexural strength, and water absorption tests are made under relevant standard in this study. The results have shown that the higher FA content increases the flow of mortar but significantly decreases the density of mixtures. The water absorption and setting time increases as the samples incorporating FA. Compressive strength of specimen with 10% FA is approximately equal to control specimen at the 91-day age. The flexural strength of specimen ranges from 7.97 MPa to 8.94 MPa at the 91-day age with the best result for samples containing 10% and 20% FA.

Key words - Fly ash; mortar; flow; compressive strength; flexural strength

1. Introduction

Fly ash (FA) is industrial waste which was generated from coal-based thermal power plants. The large amount of remaining FA is disposed in landfills with the risks of air and water pollution. This waste causes environmental problems and health impact of people in many developing countries. In Vietnam, many thermal power plants are built to meet the electricity demand for society development. Like developing cities, Mekong Delta with high consumption of electricity for development also requires coal-fired power plants. Power plants in Mekong Delta emit a large amount of FA into the environment. Therefore, finding the feasible solutions to this problem is very necessary.

The industry of cement manufacture notably contributes to CO_2 emissions which cause the environmental issue. FA includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline), aluminium oxide (Al_2O_3) and calcium oxide (CaO). Therefore, the use of FA in cementitious material sector is considered as potential approach and increases the interest for recent decades because of its potential to improve the durability and reduce carbon dioxide emissions. A large number of studies have been conducted to investigate the role of FA in cement hydration and the pozzolanic reaction mechanism. FA is known to be a good pozzolanic material for use in concrete, and many kinds of research have established its effect on the physical properties and pore structure of concrete [1]. The use of FA in cement and concrete provides a number of advantages. Because of the small sizes of FA particles, the cement pastes produced with FA became smoother, which allows better bonding between aggregate and cement, and results in a more durable and impervious concrete [2]. Because FA particles are hard and have round shape, concrete workability increases without adding extra water [3]. The hydration products of FA with calcium hydroxide ($Ca(OH)_2$) reduce the pores, in this way more strength and durable concrete is obtained [4, 5]. In addition, FA positively affects sulfate resistance, hydration heat, alkali–silicate reactions, and abrasion resistance [6-8]. Furthermore, with the use of FA in concrete, significant energy savings and reductions in CO_2 emission are provided and resources are conserved [9,10]. In Vietnam, P. H. Khang assumes that the source of FA waste in Vietnam from the factories is huge and some measures are applied, but there is no specific data on grading and impact of FA (2010) [11]. N. Q. Phu (2011) showed that flexural strength and compressive strength of concrete with FA is 2.5 MPa and 15 MPa, respectively [12]. P. T. Duc (2013) believed the strength of concrete using FA increases about 16% to 25% compared to reference specimen [13]. The study of “recycling fly ash from EVA (Ethylene-vinyl acetate) composite thermal power plants / FA” showed that fly ash disperses well in EVA around 10% [14]. However, limited studies support experimental data about the effect of FA in Mekong delta on the properties of mortar.

The purpose of the present study is to investigate the properties of mortar with and without the addition of FA. The mortars are produced at a water-to-binder ratio of 0.5, with fly ash replacements from 0 to 50%. The physical and mechanical properties of specimens are evaluated under various tests such as flow, density, compressive strength, flexural strength, and water absorption. Moreover, scanning electron microscopy (SEM) analysis is used to evaluate the morphology of cement and FA.

2. Materials and experimental works

2.1. Materials

PCB40 cement was used to produce the mortar. The properties of cement are satisfied according to Vietnam standard TCVN 6016, with specific gravity of 2.97 g/cm^3, and 28-day compressive strength of 40.7MPa. The initial and final setting time were 105 minutes and 165 minutes, respectively. The tap water that was used as the mixing fluid came from the local water factory. FA was collected from Duyen Hai power plant located in Tra Vinh province, Vietnam. The specific gravity of the FA was founded to be 2.26 g/cm^3. From Figure 1, FA particles generally have spherical and smooth shape, while cement particles were irregular in shape.

Locally sourced crushing sand was used as the fine aggregate in mortar. The fineness modulus, specific gravity, and water absorption of this crushing sand were 3.38, 2.53 g/cm^3, and 1.2%, respectively.

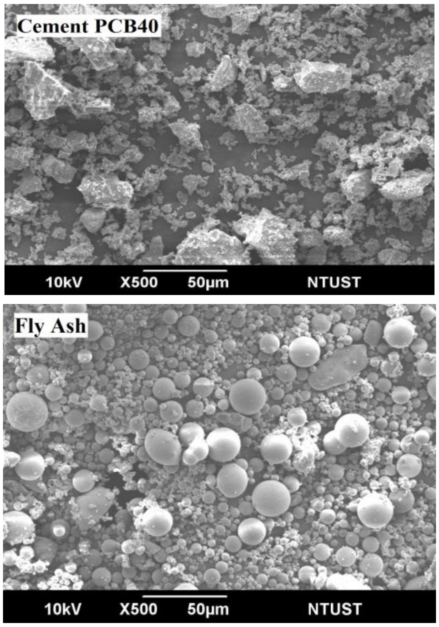

Figure 1. *SEM image of cement PCB40 & FA*

2.2. Experiment

2.2.1. Mixture proportion and testing program

Six mixtures of mortar were conducted by replacing different percentages of FA at 0%, 10%, 20%, 30%, 40%, and 50% by volume of binder (denoted as the M0, M1, M2, M3, M4, and M5, respectively). A constant water to binder ratio (w/b) of 0.5 and aggregate to binder ratio (a/b) of 2.6 was used throughout this investigation. The fresh mixtures of mortar were mixed in standard pan mixer. Then, the specimens with dimension of 40x40x160mm were cast and cured in air temperature. After 24h, the samples were removed from the steel mould and cured in water until testing day.

The flow and dry bulk density of mortar were tested in compliance with Vietnam standard TCVN 3121-3 and TCVN 3121-10, respectively. Furthermore, Vietnam standard TCVN 6017 was used to investigate initial and final setting time of mortar. The water absorption of hardened samples with and without according to Vietnam Standard TCVN 3121-18. 28-day samples dried for 24 hours at 105 Co were soaked in water at room temperature with different periods of 10 min, 30 min, 1h, 2h, 5h, 24h, and 72h to determine the water absorption. The compressive strength and flexural strength test of the mortar specimens were performed by Vietnam standard TCVN 6016 at the age of 1, 3, 7, 28, 56, and 91 days.

3. Results and discussion:

3.1. The flow of mortar:

Figure 2 shows the results of flow ability measurement of fresh mortar. In general, all of the fresh mortars exhibited uniform mixtures and good flow ability with the measured values ranging from 175 to 225 mm. As expected, addition of FA increased the flow of the mixtures. This is due to spherical and smooth shape of FA particles which promote the lubricant effect between paste and fine aggregate.

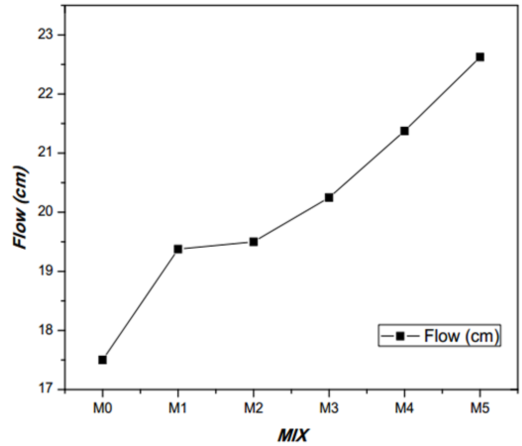

Figure 2. *The flow of fresh mixtures.*

3.2. Density of mortar

The results of dry bulk density for all mixes at 28-day ages is presented in Figure 3. The bulk density of the hardened mortar significantly decreased from 1.92 to 1.88 as FA content increased from 0 to 50%. This influence is probably due to the lower specific gravity of FA compared to specific gravity of cement.

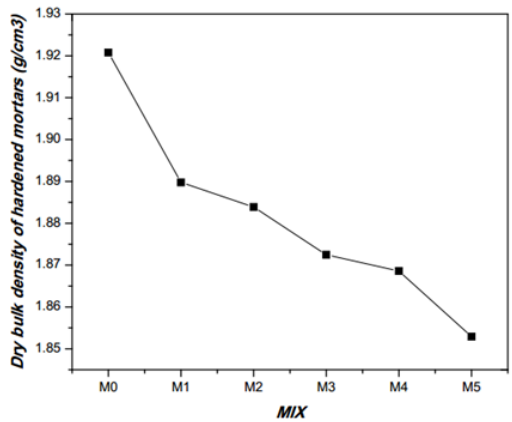

Figure 3. *Dry bulk density of hardened mortar mixtures*

3.3. Setting time

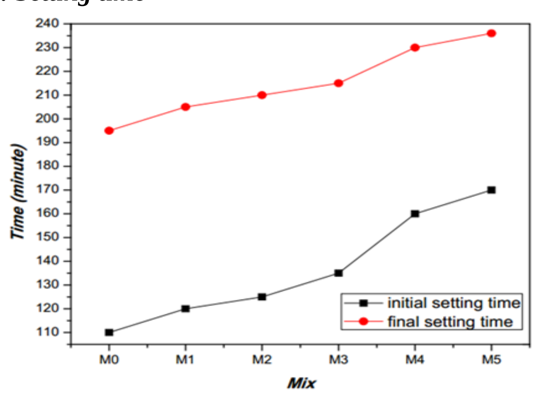

Figure 4. *Initial setting time & final setting time of fresh mortars*

Initial setting time and final setting time of the mortars with and without the addition of FA are described in Figure 4. The result showed that adding FA in mixtures increased the setting time of samples. The initial and final setting time of the fresh mortar mixtures increased from 100 to 170 minutes and from 195 to 236 minutes, respectively, while FA amount increased from 0 to 50%. This seemed to show that the strength activity index (SAI) of FA is lower than cement, confirming the low activation potential of FA in the reaction. As can be seen from Figure 5, resulting in longer setting times of higher FA content and the reaction was therefore slower.

3.4. Water absorption:

Figure 5 shows the variation in water absorption of mortar incorporating FA at different periods. As expected, higher FA replacement level was associated with greater water absorption. The use of FA at 10% and 50% of mortar binder (replacement by volume) presented a slight change in the water absorption in comparison with control mix. This increase in the water absorption is due to porous structure of mortar with addition of FA which reveals lower activation than cement.

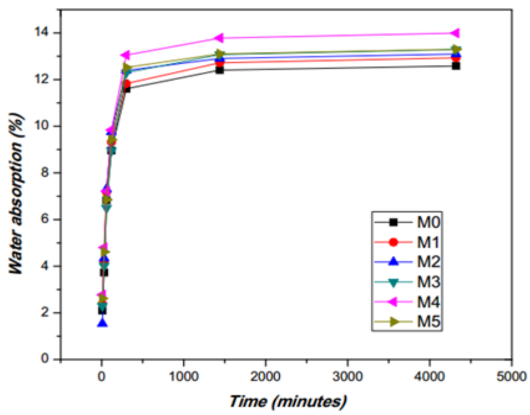

Figure 5. *Variation of water absorption of mortar with FA content*

3.5. The compressive strength of mortar:

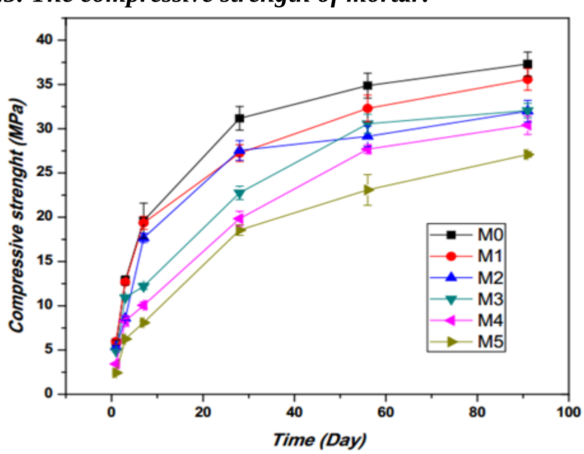

Figure 6. *Compressive strength at different ages of mortar with FA addition*

Figure 6 shows the compressive strength of all mixtures of mortar made with 0%, 10%, 20%, 30%, 40%, and 50% FA. The compressive strength of mortar decreased with an increase in the replacement level of FA. At 28-day age, the compressive strength varied from 31.2 to 18.6 MPa, while FA content increase from 0% to 50%. This reduction can be explained by the partial replacement of the cement with FA having slower reactivity, resulting in lower amount of gel and porous structure. However, the compressive strength of all tested mortars increased with specimen age. The experimental result showed that compressive strength of specimen with 10% FA was approximately equal to control specimen at the 91-day age. It implies the notable strength development capability of FA mortar due to pozzolanic reaction between SiO_2 of FA and $Ca(OH)_2$ of h ydration product of cement.

3.6. Flexural strength test of mortar

The results of flexural strength of mortar with different FA amount are presented in Figure 7. Similar to the trend of compressive strength, the flexural strength of specimens increased with cured age. Sample with 10% and 20% FA showed higher 91-day flexural strength compared to control mix. This issue is due to the contribution of FA to accelerate the hydration rate.

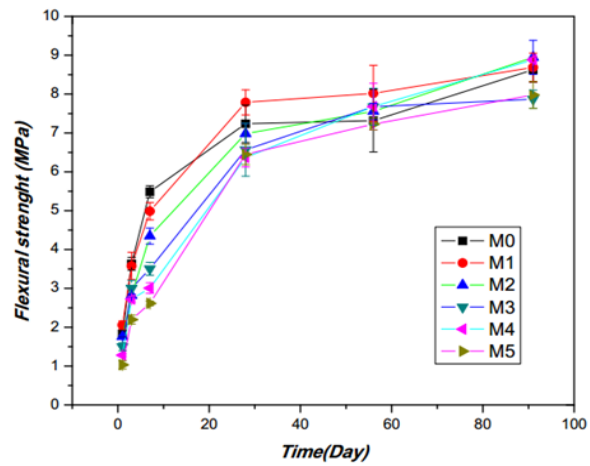

Figure 7. *Variation of flexural strength at different ages of mortar with FA addition*

4. Conclusions

Based on the experimental and analytical study, the following conclusions are summarized:

- FA amount increases the flow of mortar but remarkably reduces the density of FA.

- The water absorption and setting time present a slight increase as specimens are added with FA.

- The optimum content of 10% FA shows clear and positive effect on compressive strength and the flexural.

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