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EFFECT OF FLY ASH FINENESS ON COMPRESSIVE, FLEXURAL AND SHEAR STRENGTHS OF HIGH STRENGTH-HIGH VOLUME FLY ASH JOINTING MORTAR

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ABSTRACT: In this research, the compressive, flexural, and shear bond strengths of high strength-high volume fly ash mortar containing high calcium fly ash (HCFA) of various finenesses were studied. The mortars were made from ordinary Portland cement (OPC), HCFA, sand, water, and Type D admixture. The HCFA was from Mae Moh power station in the north of Thailand. Three types of HCFA fineness viz., as-received coarse fly ash (CF), medium fineness fly ash (MF, passed sieved No. 100), and fine fly ash (FF, passed sieve No. 200) were used to replace OPC at the levels of 0-70 % by weight of binder. The results showed that the high strength-high volume fly ash mortars with satisfactory 28-day compressive strengths between 70.0 and 114.0 MPa, shear bond strengths between 7.2 and 18.0 MPa, and flexural strengths between 15.9 and 27.6 MPa were obtained. Test results also indicated that the use of FF gave significantly higher strengths than the use of CF and MF. Specifically, the compressive strength of mortar containing 50%FF was very high at 110.0 MPa. The FF could thus be used to improve the strengths of high volume fly ash mortar for uses in various architectural and structural works requiring high strength products.

Keywords: High calcium fly ash, Fly ash fineness, High volume fly ash, High strength mortar, Shear bond strength

1. INTRODUCTION

Currently, the construction of wall in building mainly uses ready-made concrete materials in the form of concrete blocks. In the past, the concrete blocks for wall possesses low strength and thus the use is relatively limited. For diverse usage, the strength development is substantially improved such that it can be used in structural work as well [1].

One of the important use of the block is the preformed wall for the housing units. The ready-made preformed wall can be fabricated at the concrete plant and transport to the construction site. This drastically reduces the time required for the construction of building or housing complex. This results in rapid construction using concrete block panels as shown in Fig. 1. The joining of the blocks in making preformed wall required a high strength mortar such that the wall can be transported to the site without damage.

To develop a sufficiently high strength mortar, it is necessary to use a high cement content and this results in high cost. In addition, the production of cement is an energy intensive process. Coupled with the burning of calcareous material, the production of cement thus produces a large amount of carbon dioxide. For every ton of Portland cement coming out of the furnace, almost 1 ton of carbon dioxide (CO_2) was released into the atmosphere [2].

Fig.1 The rapid construction of wall using preformed concrete blocks

It is therefore important to reduce this greenhouse gas emissions into the atmosphere by using the environmental friendly cementitious material products [3] or alternatively use less cement with the use of high volume pozzolanic material to replace Portland cement. The available fly ash in large quantity is the high calcium fly ash from Mae Moh Power station in the north of Thailand which has been shown to be a good pozzolan. This amount of calcium is rather high and increases with the increasing depth of coal mining [4]. The use of this fly ash in concrete increases the porosity, but the average pore size is reduced [5, 6] and the interfacial zone between aggregate and matrix is improved [7].

In order to utilize the fly ashes effectively, the coarse portions of fly ashes have to be processed. Grinding and classification can be used to increase the fineness of the fly ash. It has been demonstrated that the compressive strength of concrete with fly ash can be improved by using finer fly ashes [8-13]. In addition, the use of fine fly ash with spherical particle and smooth surface result in some better mechanical properties i.e. to increase the strength and improve the durability of mortar and concrete compared to the coarse fly ash [8-10]. The shrinkage is also in reduced compared to the control but slightly increased compared to the use of coarser fly ash [14].

Therefore, in this study, the use of high calcium fly ash with different finesses to improve the strength of high volume fly ash jointing mortar is studied. The as-received fly ash, the medium fineness fly ash passed sieve No. 100 and the fine fly ash passed sieve No. 200 were used to produce high strength mortar. The results will enable the use of fly ash more effectively through the classification and high volume usage with ensured high strength.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Materials used in this research consisted of ordinary Portland cement (OPC), river sand, water and high calcium fly ash (HCFA). The HCFA was the by-products from Mae Moh power station in Lampang province, northern Thailand. It was classified to three lots of HCFA fineness viz., as-received coarse fly ash (CF), medium fineness fly ash passed sieved No. 100 (MF), and fine fly ash passed sieve No. 200 (FF). The physical properties of materials are shown in Table 1.

The morphology of HCFA by SEM as shown in Fig. 2 indicated that the shape of HCFA was spherical with smooth surface. The chemical compositions of HCFA are shown in Table 2. The specific gravity of HCFA was 2.66 with median particle size of 18.6 µm. The HCFA consisted of a high content of 36.20% SiO_2, 15.52% Al_2O_3, 14.25% Fe_2O_3, and 22.57% CaO with the loss on ignition (LOI) of 0.88%. The XRD of HCFA as shown in Fig. 3 indicated the high amorphous content with relatively large hump around 22-38 $^{o}2\Theta$.

Table 1 The physical properties of materials

Materials	Sand	OPC	HCFA
Specific gravity	2.61	3.15	2.66
Median particle size (µm)	-	14.6	18.6
Fineness modulus	2.65	-	-
Unit weight (kg/m^3)	1360	1440	-
Water absorption (%)	1.17	-	-

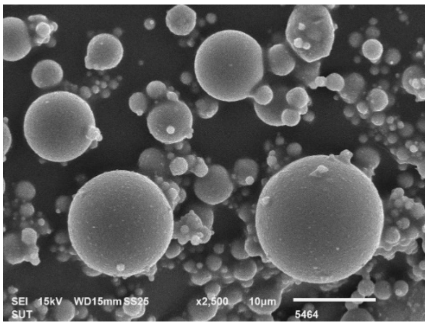


Fig.2 The morphology of HCFA by SEM

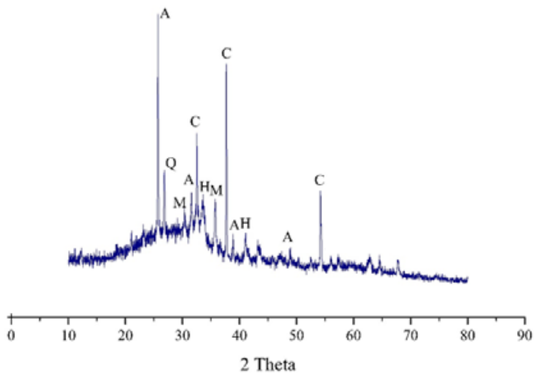


Fig.3 The XRD of HCFA. M-Maghemite: Fe_2O_3; Fe_3O_4; H-Hematite; A-Anhydrite; C-Calcium Oxide; Q-Quartz.

2.2 Mix Proportion

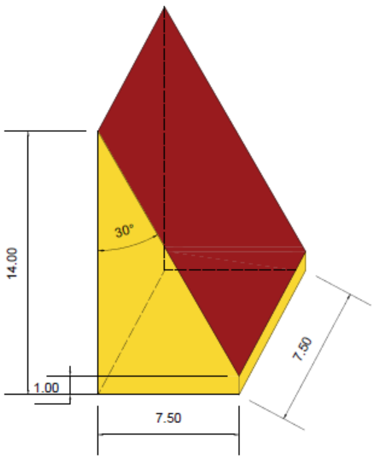
2.2.1 The HCFA contents

To study the effect of HCFA fineness, as-received coarse fly ash (CF), medium fineness fly ash passed sieved No. 100 (MF), and fine fly ash passed sieve No. 200 (FF) were used to replace OPC at the levels of 0-70 % by weight for the manufacturing of high strength jointing mortars.

The compressive strength, flexural and shear bond strengths of high volume fly ash-high strength mortar were determined.

Table 2 Chemical composition of materials (by weight)

Chemical compositions (%)	HCFA	OPC
SiO_2	36.20	20.8
Al_2O_3	15.52	4.7
Fe_2O_3	14.25	3.4
CaO	22.57	65.3
K_2O	1.63	0.4
Na_2O	0.33	0.1
SO_3	8.9	2.7
LOI	0.88	0.9



a. Dummy Bottom Section

b. testing of shear bond strength

Fig.4 The shear bond strength test of high volume fly ash-high strength mortar

2.2.2 Details of Mixing

All mixtures were made with binder to sand ratio of 1:0.33, superplasticizer (SP) of 0.50 % of binder and water to binder ratio of 0.24. For mixing, OPC and HCFA were firstly mixed together until the mixture was homogenous. Next, sand was added and mixed for 5 min. Finally, water and SP were added and mixed for 3 minutes to obtain a homogenous mixture.

The fresh high strength mortar was placed into 50x50x50 mm cube molds, 75x75x150 mm and 75x75x300 mm prism molds. The specimens were demolded at 1 day and stored in water.

2.3 Details of Test

2.3.1 Compressive strength

The cube specimens size 50x50x50 mm were tested to determine the compressive strength in accordance with ASTM C109/C109M-16a [15]. The reported compressive strengths were the average of three samples.

2.3.2 Shear bond strength

The prism specimens size 75x75x150 mm were tested to determine the shear bond strength in accordance with ASTM C882/C822M [16]. The reported shear bond strength was the average of three samples. The sample bond strength of high volume fly ash-high strength mortar with concrete by slant shear are shown in Fig. 4. The 28 day-strength of dummy concrete was 70.0 MPa. The contact surface of the dummy concrete was cut surface by diamond saw.

2.3.3 Flexural strength

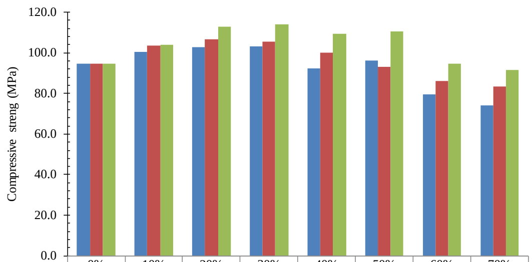
The prism specimens size 75x75x300 mm were tested to determine the flexural strength in accordance with ASTM C293-02 [17]. The reported flexural strength was the average of three samples.

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength and Density

The results of compressive strength of high volume fly ash-high strength mortar are shown in Fig. 5. The compressive strength increased with increasing HCFA content from 0 to 30 % by weight. The compressive strength development from all fly ash was quite good, especially the fine fly ash. At low replacement level, the compressive strengths of fly ash mortar were higher than mortar without fly ash due to the pozzolanic reaction of fly ash and the filling effect [10]. In contrast, for the high volume HCFA replacement, the strength started to decrease with more than 30 % replacement. With more than 50% replacement the compressive strengths were less than that of the control. For example, the compressive strengths at 28 days of mixes with CF with volume of HCFA of 0, 10, 20, 30, 40, 50, 60, and 70 % by weight were 94.7, 100.3, 102.6, 103.3, 92.4, 96.2, 79.6, and 74.0 MPa, respectively.

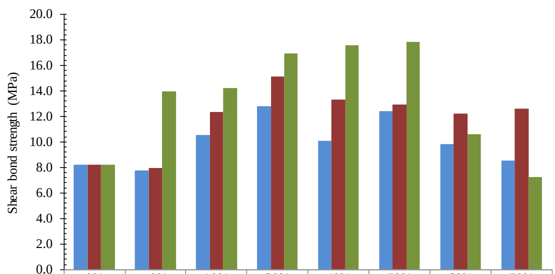
With regards to types of HCFA fineness, the compressive strength increased with increasing HCFA fineness. The filling effect of fly ash contribute to the relatively good compressive strength development of the concrete containing HCFA. The used of finer fly ash resulted in further enhancement of the compressive of concrete [8-10]. For example, the compressive strengths at 28 days of 30 % fly ash with HCFA fineness of CF, MF, and FF were 103.3, 105.3, and 114.0 MPa, respectively.



	0%	10%	20%	30%	40%	50%	60%	70%
CF	94.7	100.3	102.6	103.3	92.4	96.2	79.6	74.0
MF	94.7	103.6	106.6	105.3	100.0	93.0	86.0	83.2
FF	94.7	104.1	113.0	114.0	109.3	110.6	94.6	91.6

Fig.5 Compressive strength of high volume fly ash-high strength mortar at 28 days

3.2 Shear Bond Strength



	0%	10%	20%	30%	40%	50%	60%	70%
CF	8.2	7.8	10.6	12.8	10.1	12.4	9.8	8.6
MF	8.2	8.0	12.4	15.1	13.3	12.9	12.2	12.6
FF	8.2	14.0	14.2	16.9	17.6	17.9	10.6	7.2

Fig.6 Shear bond strength of high volume fly ash-high strength mortar at 28 days

The results of 30º slant shear bond strength test of high volume fly ash-high strength mortar are shown in Fig. 6. For the mixes with CF and MF, the shear bond strength increased with the increasing volume of HCFA from 0-30 % fly ash. For example, the shear bond strength at 28 days of mixes with MF with volume of HCFA of 0, 10, 20, 30, 40, 50, 60, and 70 % by weight were 8.2, 7.8, 10.6, 12.8, 10.2, 12.4, 9.8, and 8.6 MPa, respectively. The increase in the replacement levels resulted in a drop in the strength of the samples. However, the results also indicated that the strength of the 70% fly ash mortar was still comparable to that of the control. For the fine fly ash, the shear bond strength of FF increased with the increasing volume of HCFA from 0-50 % replacement levels. The increased shear bond strength was due to increased compressive strength with the increase in pozzolanic reaction of fly ash and the filling effect of the fine fly ash particles [9].

a. 10 % HCFA b. 20 % HCFA

c. 30 % HCFA d. 40 % HCFA

e. 50 % HCFA f. 70 % HCFA

Fig.7 The failure of shear bond strength

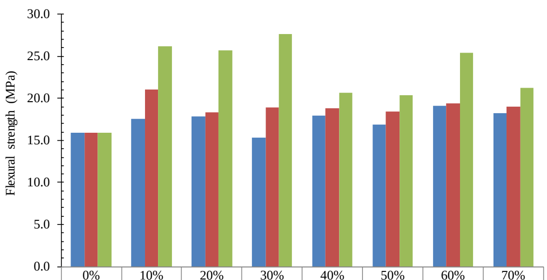
With regards to types of HCFA fineness, the shear bond strength increased with increasing HCFA fineness. For example, the shear bond strength at 28 days of 30 % fly ash with HCFA fineness of CF, MF, and FF were 12.8, 15.1, and

16.9 MPa, respectively. This is because the high fineness HCFA has high surface area resulting in the high internal bond strength of the cement paste [18] and thus resulted in the high shear bond strength between high strength mortar and old concrete substrate.

In addition, the fracture characteristics of slant shear prisms are shown in Fig. 7. The slant shear bond prisms failed in the monolithic mode where cracks were formed in both section of high strength mortar and old concrete substrate [19] which indicated the relative high resistance to damage of high strength mortar and high bonding between the two surfaces.

3.3 Flexural Strengths

The results of flexural strength of high volume fly ash-high strength mortar are shown in Fig. 8. For the mixes with CF and MF, the flexural strengths increased with the incorporation of the fly ash. For example, the flexural strength at 28 days of mixes with MF with volume of HCFA of 0, 10, 20, 30, 40, 50, 60, and 70 % by weight were 15.9, 21.1, 18.3, 18.9, 18.8, 18.4, 19.4, and 19.0 MPa, respectively. Moreover, the flexural strength of FF were further increased with the incorporation of FF especially at the 10 – 30 % replacement levels. Normally, the trend of flexural strengths was similar to those of compressive strengths [20]. In this case, with the incorporation of fly ash, the flexural strengths were improved slightly better than those of compressive strengths.



	0%	10%	20%	30%	40%	50%	60%	70%
CF	15.9	17.5	17.8	15.4	18.0	16.9	19.1	18.2
MF	15.9	21.1	18.3	18.9	18.8	18.4	19.4	19.0
FF	15.9	26.2	25.7	27.6	20.7	20.3	25.4	21.3

Fig.8 Flexural strengths of high volume fly ash-high strength mortar at 28 days

With regards to types of HCFA fineness, the flexural strength of base line was 15.9 MPa and the flexural strength increased with increasing of HCFA fineness. For example, the flexural strength at 28 days of 10 % fly ash with HCFA fineness of CF, MF, and FF were 17.5, 21.1, and 26.6 MPa, respectively and representing an average improvement of 67 % from base line. The increasing of flexural strength was due to the increase in the reaction products from increased reaction of fine HCFA. This was associated with the improvement of compressive strength and shear bond strength of high strength mortar which led to overall improvement in the flexural strength [19].

4. CONCLUSIONS

Based on the obtained data, the following conclusions can be drawn:

1. The increasing in HCFA fineness resulted in the improvement of the compressive, shear bond and flexural strengths of mortar.
2. For compressive strength, the optimum volume of HCFA was 30 % with substantial increase in compressive strength.
3. For shear bond strength, the behavior was similar to that of compressive strength. However, the optimum replacement level of fine FF was increased to 50 % suggesting that a larger amount fly ash could be incorporated providing that its particle was fine.
4. For the flexural strength, the trend of results was similar to the improvements in compressive and shear bond strengths. The improvement with the incorporation of FF was more evident in the flexural strength. The improvement represented an average of 67 % from base line for the 10 % replacement level.
5. The results showed that high strength-high volume fly ash mortars with satisfactory 28-day compressive strengths of between 70 and 114 MPa, shear bond strength between 7.2 and 18.0 MPa, and flexural strength between 15.9 and 27.6 MPa were obtained. Moreover, test results indicated that the use of FF gave significantly higher strengths than the use of CF and MF. The FF could thus be used to improve the strengths of OPC mortar and used as an alternative mortar for various architectural and structural works requiring high strength products.

5. ACKNOWLEDGEMENTS

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