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Compressive Strength of Blended Portland Cement Mortars Incorporating Fly Ash and Silica Fume at High Volume Replacement*

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ABSTRACT

Fly ash has been widely used as a replacement of Portland cement at high content levels, but the compressive strength of Portland cement blended with fly ash is lower at early ages. Thus, this study compares the compressive strength of ternary blended Portland cement mortars incorporating fly ash (40-70 wt%) and silica fume (5-10 wt%) with binary blended Portland cement mortars incorporating fly ash only. Blended Portland cement mortars were designed with a constant water/binder ratio of 0.485 and the flow table tested was carried out. A fine aggregate to binder ratio of 2.75 was used. The compressive strength of all blended Portland cement mortars that cured in water at 23 °C was tested at 28 days. The results show that the flow of blended Portland cement mortars increased with increasing fly ash content and tended to decrease with increasing silica fume content, at the same replacement level. Moreover, the compressive strength of blended Portland cement mortars decreased with increasing fly ash content. However, compressive strength gains were obtained from ternary blended Portland cement mortars incorporating silica fume, tending to increase with increasing silica fume content.

Keywords: Blended Portland cement, Fly ash, Silica fume, Compressive strength

INTRODUCTION

High volume fly ash (HVFA) has been widely investigated. In commercial practice, the dosage of fly ash (FA) is limited to 15-20% by mass of the total cementitious material. Usually, this amount has a beneficial effect on the workability and cost economy of concrete, but it may not be enough to sufficiently improve the durability to sulfate attack, alkali-silica expansion and thermal cracking. Forthese durability properties, HVFA with 50% or more fly ash, by mass of the cementitious material, has been studied (Mehta, 2004). The used of HVFA in self-compacting concrete reduces the dosage of superplasticizer, which is needed

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to obtain a similar slump flow as concrete made with Portland cement (PC) only due to the spherical-shaped particles of fly ash. Also, the use of fly ash improves rheological properties and reduces cracking of concrete due to its lower heat of hydration (Bouzoubaa and Lachemi, 2001). However, the strengths of HVFA concrete are lower than that of pure Portland cement concrete, especially at early ages, due to the dilution effect and very low pozzolanic reaction of fly ash (Bouzoubaa et al., 2001; Atis, 2005; Dinakar et al., 2008; Papayianni and Anastasiou, 2010; Duran-Herrera et al., 2011).

Previous studies have found that the use of fly ash with silica fume (SF) in ternary blended cement enhances mechanical properties compared to binary blended cement with fly ash alone, especially at early ages (Huang, 1997; Poon et al., 2001; Kilic et al., 2003; Nassif et al., 2005; Erdem and Kirca, 2008). Nochaiya et al., (2010) investigated ternary blends of fly ash, silica fume and Portland cement using an extensive range of mixes. They found that incorporating fly ash with silica fume increased the compressive strength of concrete at early ages up to 145%, with the highest strength obtained with 10 wt% silica fume. In addition, using fly ash with silica fume in ternary blended cement enhances the workability of binary blended cement with silica fume alone (Long et al., 2002; Sharfuddin Ahmed et al., 2008; Shannag, 2011). Thus, this study investigated the compressive strength of binary and ternary blended cement mortar using fly ash and silica fume as a cement replacement at high levels.

MATERIALS AND METHODS

Portland cement type I, fly ash (obtained from Mae Moh power plant in Lampang, Thailand) and undensified silica fume grade 920-U (produced by Elkem) were used in this study. The chemical compositions of Portland cement, fly ash and silica fume powder are given in Table 1. XRD patterns of Portland cement, fly ash and silica fume are shown in Figure 1.

Table 1. Chemical compositions of the materials used in this research.

Chemical composition (%)			
	PC	FA	SF
SiO_2	20.64	45.37	93.55
Al_2O_3	4.85	20.65	0.56
CaO	63.62	10.43	1.13
Fe_2O_3	3.17	12.31	0.17
MgO	1.14	2.13	0.75
Na_2O	0.51	1.33	0.14
K_2O	0.81	1.50	1.05
P_2O_5	0.32	0.24	0.53
TiO_2	0.21	0.52	0.002
SO_3	2.75	2.53	1.01
LOI	2.08	3.00	1.16

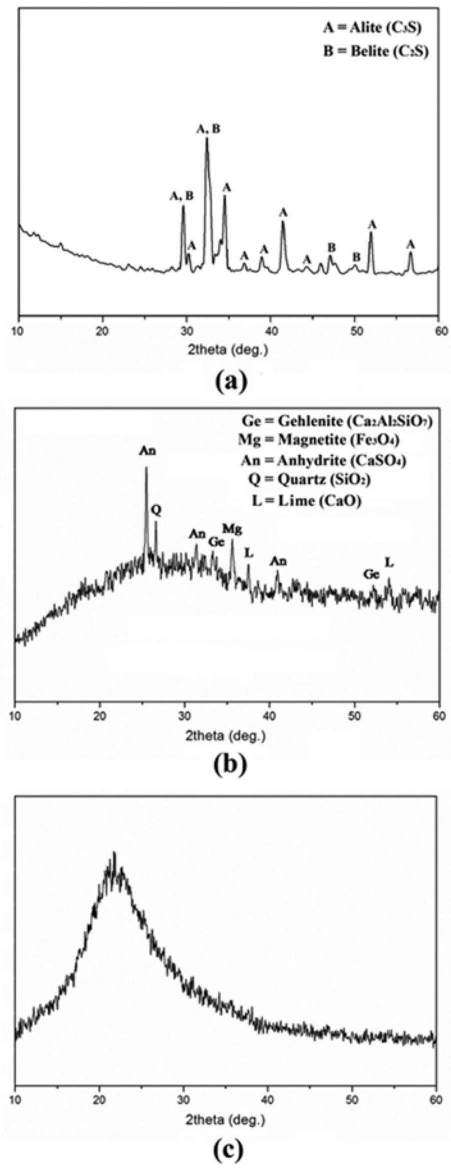

Figure 1. XRD patterns of materials used in this research (a) Portland cement (b) fly ash and (c) silica fume.

The XRD pattern indicates that Portland cement consists mainly of Alite (C_3S) and Belite (C_2S) phases. In addition, the XRD patterns of fly ash and silica fume show a broad peak in the range of 20-30° (2θ), which is a characteristic of amorphous SiO_2 phases. However, fly ash also consisted of mainly crystalline phases of gehlenite ($Ca_2Al_2SiO_7$), magnetite (Fe_3O_4), anhydrite ($CaSO_4$), quartz (SiO_2) and lime (CaO). The physical characteristics, such as morphology and particle size, of Portland cement, fly ash and silica fume were investigated using a scanning electron microscope. The micrograph of Portland cement reveals an irregular shape, while fly ash and silica fume are spherical (Figure 2). In addition, river sand with specific gravity of 2.65 was used as a fine aggregate of mortar.

In this study, binary and ternary blended Portland cement mortars were investigated using fly ash and silica fume as a Portland cement replacement. Fly ash replaced part of the cement at 40, 45, 50, 55, 60, 65 and 70% by weight. Silica fume replaced part of the cement at 5 and 10% by weight, respectively. A fine aggregate to binder ratio of 2.75 and water to binder ratio of 0.485 were used. In addition, flow table was also measured. The mix proportions and mix design are summarized in Table 2. The mortar mixes were mixed and cast into 50x50x50 mm moulds and compacted using a vibrating table. The mortar specimens were stored in moulds for 24 h. After the specimens were demoulded, they were cured in water for 28 days and then the compressive strength tested were carried out.

Table 2. Mix proportions of blended cement mortars.

Mix proportions			
Mixes	PC (%)	FA (%)	SF (%)
100PC	100	-	-
50FA	50	50	-
60FA	40	60	-
70FA	30	70	-
5SF	95	-	5
10SF	90	-	10
45FA5SF	50	45	5
55FA5SF	40	55	5
65FA5SF	30	65	5
40FA10SF	50	40	10
50FA10SF	40	50	10
60FA10SF	30	60	10

RESULTS

Flow test

Workability property of binary and ternary blended cement mortar was tested through the measurement of flow table (Table 3). The flow table of binary blended Portland cement mortar with silica fume was lower than the Portland cement control and tended to decrease with increasing silica fume content. However, flow table of ternary blended Portland cement mortar with fly ash and silica fume content increased compared to binary blended Portland cement mortars with only silica fume content. Moreover, flow table of ternary blended Portland cement mortars increased with increasing fly ash content.

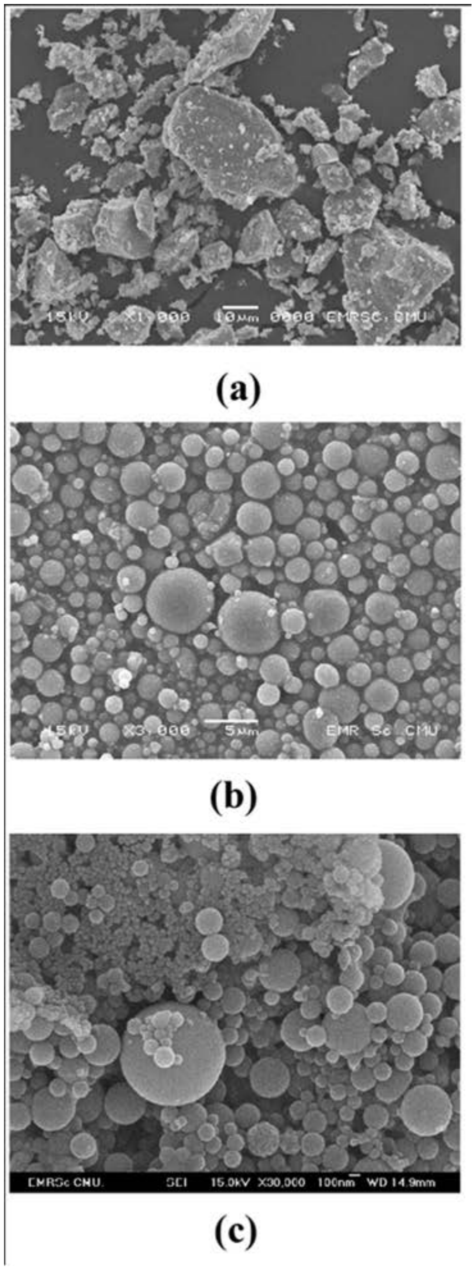

Figure 2. SEM micrographs of materials used in this research: (a) Portland cement, (b) fly ash and (c) silica fume.

table 3. Flow table tests of blended cement mortar.

Mixes	Flow table (mm)
OPC	101.5
50FA	142.8
60FA	N.A.*
70FA	N.A.*
5SF	66.8
10SF	47.0
45FA5SF	99.0
55FA5SF	109.3
65FA5SF	112.9
40FA10SF	65.8
50FA10SF	76.0
60FA10SF	83.8

Note: *Not available, cannot be measured due to overflow (>150 mm).

Compressive strength

Compressive strength of binary blended cement mortars at 28 days is shown in Figure 3. The compressive strength of binary blended cement mortars containing fly ash was lower than the Portland cement control and tends to decrease with increasing fly ash content. While the compressive strength of binary blended cement mortars with silica fume at 5 and 10 wt.% was higher than the Portland cement control.

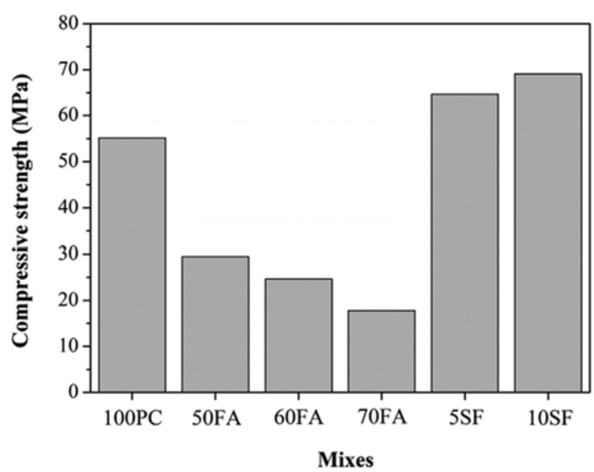

Figure 3. Compressive strength of Portland cement and binary blended cement mortars.

Figures 4-6 show the compressive strength of ternary blended Portland cement mortars at 50, 60 and 70 wt% cement replacement in comparison to Portland cement control mortars, respectively. The compressive strength of ternary blended cement mortars are higher than binary blended cement mortars, at the same level replacement. Moreover, the compressive strength of ternary blended Portland cement mortars increases with increasing silica fume content. However, compressive strength of all ternary blended cement mortars at 50, 60 and 70 wt% cement replacement are still lower than that of the Portland cement control.

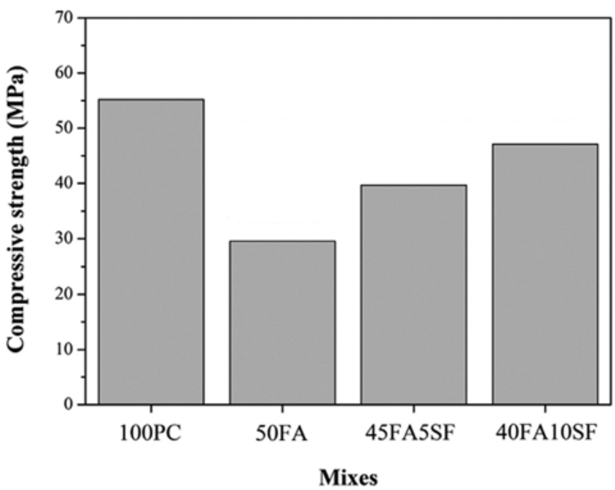

Figure 4. Compressive strength of Portland cement, binary and ternary blended cement mortars at 50% replacement.

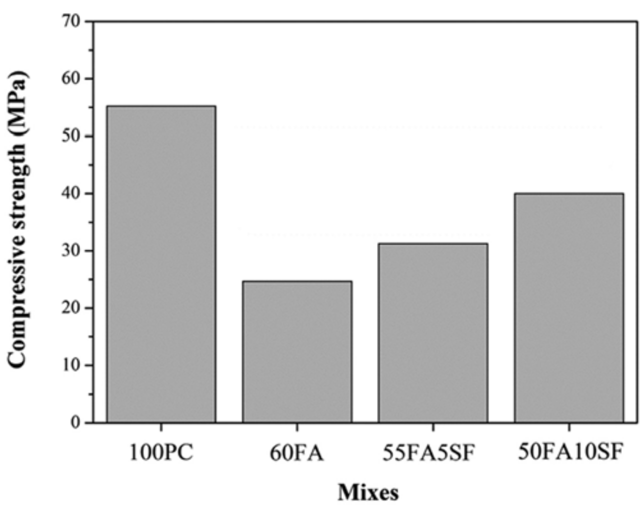

Figure 5. Compressive strength of Portland cement, binary and ternary blended cement mortars at 60% replacement.

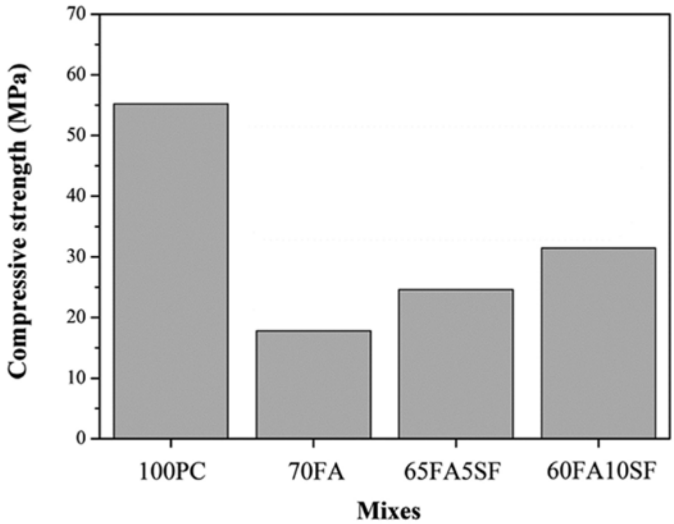

Figure 6. Compressive strength of Portland cement, binary and ternary blended cement mortars at 70% replacement.

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This study investigated the compressive strength of binary and ternary blended Portland cement mortars using fly ash and silica fume as a Portland cement replacement. For the workability property of the samples, flow table of binary blended Portland cement mortars with silica fume was lower than the Portland cement control and tended to decrease with increasing silica fume content. The use of silica fume reduces the workability mortar due to its very high specific surface area (Mostafa et al., 2010). However, flow table of ternary blended Portland cement mortar increased with increasing fly ash content. This is due to the mostly spherical shape of the fly ash particles, compared to the irregular shapes of Portland cement (Siddique, 2004; Khatib, 2008). Thus, the workability of blended Portland cement mortar with only silica fume replacement can be improved by also incorporating fly ash.

The compressive strength of binary blended Portland cement mortars containing fly ash was lower than the Portland cement control and tended to decrease with increasing fly ash content. The reduction of compressive strength of binary blended cement containing fly ash is due to its slow pozzolanic reaction and the dilution effect (Papayianni and Anastasiou, 2010; Duran-Herrera et al., 2011; Wongkeo et al., 2012). While the compressive strength of binary blended cement mortars with silica fume at 5 and 10 wt% was higher than the Portland cement control. This is due to the high pozzolanic reaction and micro filler effect of silica fume (Erdem and Kirca, 2008; Elahi et al., 2010).

For ternary blended Portland cement mortars, the compressive strength of ternary blended Portland cement mortars was higher than binary blended Portland cement mortars at the same replacement levels and tended to increase with increasing silica fume content. The improvement of the compressive strength of ternary blended Portland cement mortars is due to the higher pozzolanic reac- tion of silica fume than that of fly ash and the micro filler effect of silica fume. However, compressive strength of all ternary blended cement mortars at 50, 60 and 70 wt% cement replacement was still lower than that of the Portland cement control. This is because the micro filler effect and pozzolanic reaction cannot compensate for the dilution effect at the tested age (28 days).

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