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Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume

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ABSTRACT

The influence of high-calcium fly ash and silica fume as a binary and ternary blended cement on compressive strength and chloride resistance of self-compacting concrete (SCC) were investigated in this study. High-calcium fly ash (40–70%) and silica fume (0–10%) were used to replace part of cement at 50, 60 and 70 wt.%. Compressive strength, density, volume of permeable pore space (voids) and water absorption of SCC were investigated. The total charge passed in coulombs was assessed in order to determine chloride resistance of SCC. The results show that binary blended cement with high level fly ash generally reduced the compressive strength of SCC at all test ages (3, 7, 28 and 90 days). However, ternary blended cement with fly ash and silica fume gained higher compressive strength after 7 days when compared to binary blended fly ash cement at the same replacement level. The compressive strength more than 60 MPa (high strength concrete) can be obtained when using high-calcium fly ash and silica fume as ternary blended cement. Fly ash decreased the charge passed of SCC and tends to decrease with increasing fly ash content, although the volume of permeable pore space (voids) and water absorption of SCC were increased. In addition when compared to binary blended cement at the same replacement level, the charge passed of SCC that containing ternary blended cement was lower than binary blended cement with fly ash only. This indicated that fly ash and silica fume can improve chloride resistance of SCC at high volume content of Portland cement replacement.

1. Introduction

Nowadays, high-volume fly ash (HVFA) concrete, with 50% or more of cement replaced by fly ash (FA) has been studied extensively. HVFA is often used to achieve good slump flow of self-compacting concrete (SCC). SCC is a new category of high-performance concrete characterized by its ability to spread into place under its own weight without the need of vibration, and self-compact without any segregation [1,2]. The use of FA in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow as for concrete made with Portland cement [3]. Also, the use of FA improves rheological properties and reduces cracking of concrete due to lower heat of hydration [4,5]. However, the strengths of HVFA concrete are lower than that of pure Portland cement concrete, especially at early age due to the dilution effect and very low pozzolanic reaction [6–10].

Currently, the trend of SCC utilization is extensively in many subject area includes in marine area. It well known that corrosion of reinforcement embedded in concrete due to chloride ion attack is one of the most significant durability problems of concrete that subjected in marine zone. Generally, free chlorides play a vital role in the deterioration of steel reinforcement in concrete. Supplementary cementitious materials (SCM), such as fly ash, silica fume, ground granulated blast-furnace slag, and metakaolin have a significant impact on the ability of concrete to resist the penetration of chloride ions due to chlorides binding capacity of these materials. The process of chloride binding can be classified into two categories namely chemical binding and physical binding. The strongly bound chlorides are chemical binding. Chloride ions can react chemically with tricalciumaluminate (C_3A) to form calcium chloroaluminates ($3CaO{\cdot}Al_2O_3{\cdot}CaCl_2{\cdot}10H_2O$:Friedel's salt) [11,12]. In addition, chloride ions can be physically adsorbed on the surface of the solid phases of hydrated products like C–S–H gel and other products of reactions [13,14].

Due to the low compressive strength at the early age, silica fume (SF) was used incorporating with FA and found that the compressive strength was improved [15–17]. However, there are a few study focused on the use of FA and SF in term of ternary blended cement on chloride penetration of SCC, especially the use of high-calcium fly ash incorporating with SF at high cement

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Table 1
Chemical compositions and physical properties of Portland cement, fly ash and silica fume.

Oxide	Percent chemical composition (%)		
	Portland cement	Fly ash	Silica fume
SiO_2	20.64	36.84	93.55
Al_2O_3	4.85	19.99	0.56
CaO	63.62	18.55	1.13
Fe_2O_3	3.17	15.25	0.17
MgO	1.14	2.22	0.75
Na_2O	0.51	0.80	0.14
K_2O	0.81	2.76	1.05
P_2O_5	0.32	0.21	0.53
TiO_2	0.21	0.53	0.00
SO_3	2.75	2.79	1.01
Loss on ignition	2.08	0.03	1.16
Physical properties			
BET surface area (m^2/g)	2.24	1.34	18.09
Specific gravity (g/cm^3)	3.15	2.1	2.2

Table 2
Physical properties and sieve size distributions of crushed limestone and river sand.

Sieve number	Sieve size (mm)	Percentage passing (%)	
		Limestone	River sand
1	25 (mm)	100	100
3/4	19	82.76	100
3/8	9.5	10.41	100
#4	4.75	0.1	98.7
#8	2.36	0	85.3
#16	1.18	0	57.7
#30	0.6	0	23
#50	0.3	0	3.5
#100	0.15	0	0.6
Specific gravity		2.65	2.6

replacement level. Therefore, in this study, the chloride penetration of SCC produced using high-calcium fly ash and SF was investigated at high level of cement replacement. In addition, compressive strength, apparent density, and volume of permeable pore space (voids) and water absorption of SCC were also tested.

2. Experimental details

2.1. Materials

Ordinary Portland cement type I (PC) of The Siam Cement Public Company Ltd., Lampang, Thailand was used. Fly ash (FA) obtained from Mae Moh power plant in Lampang, Thailand and undensified silica fume (SF) grade 920-U obtained by Elkem Silicon Materials Ltd., Singapore were used in partial replacement of cement by weight in different compositions. The chemical compositions and physical properties of Portland cement, fly ash

Table 3
The mix proportions of SCC.

Mix	Proportion (kg/m^3)						
	Water	PC	FA	SF	Fine aggregate	Coarse aggregate	Superplasticizer (%)
W/B = 0.3							
PC	180	600	0	0	1084	595	1.19
50FA	180	300	300	0	958	595	0.25
60FA	180	240	360	0	933	595	0.17
70FA	180	180	420	0	908	595	0.12
5SF	180	570	0	30	1072	595	1.33
10SF	180	540	0	60	1059	595	1.43
45FA5SF	180	300	270	30	958	595	0.37
55FA5SF	180	240	330	30	933	595	0.30
65FA5SF	180	180	390	30	908	595	0.20
40FA10SF	180	300	240	60	958	595	0.60
50FA10SF	180	240	300	60	933	595	0.48
60FA10SF	180	180	360	60	908	595	0.38
W/B = 0.35							
PC	180	514	0	0	1131	621	1.50
50FA	180	257	257	0	1023	621	0.26
60FA	180	206	309	0	1001	621	0.19
70FA	180	154	360	0	980	621	0.13
5SF	180	489	0	26	1120	621	1.60
10SF	180	463	0	51	1110	621	1.75
45FA5SF	180	257	231	26	1023	621	0.40
55FA5SF	180	206	283	26	1001	621	0.32
65FA5SF	180	154	334	26	980	621	0.22
40FA10SF	180	257	206	51	1023	621	0.62
50FA10SF	180	206	257	51	1001	621	0.50
60FA10SF	180	154	309	51	980	621	0.40
W/B = 0.4							
PC	180	450	0	0	1166	640	1.80
50FA	180	225	225	0	1072	640	0.26
60FA	180	180	270	0	1053	640	0.21
70FA	180	135	315	0	1034	640	0.13
5SF	180	428	0	23	1157	640	1.90
10SF	180	405	0	45	1147	640	2.10
45FA5SF	180	225	203	23	1072	640	0.43
55FA5SF	180	180	248	23	1053	640	0.34
65FA5SF	180	135	293	23	1034	640	0.28
40FA10SF	180	225	180	45	1072	640	0.64
50FA10SF	180	180	225	45	1053	640	0.52
60FA10SF	180	135	270	45	1034	640	0.46