[illegible]

อายุ	[illegible]	[illegible]	[illegible]	พื้นที่ ซม^2	น้ำหนัก ก	[illegible]	[illegible]	[illegible]	[illegible]
3.5 ชม. 30/12/2543 11.00	มาตรฐาน	1	4.010x5.150	25.2663	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		2	5.010x5.050	25.3005	[illegible]	[illegible]	[illegible]		
		3	5.030x5.100	25.6530	[illegible]	[illegible]	[illegible]		
	Autogenous	1	5.050x5.050	25.5025	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		2	5.060x5.130	25.9073	[illegible]	[illegible]	[illegible]		
		3	5.010x5.020	25.1502	[illegible]	[illegible]	[illegible]		
	75 C	1	5.000x5.240	26.2000	[illegible]	[illegible]	[illegible]	[illegible]	
		2	5.180x5.180	26.8324	[illegible]	[illegible]	[illegible]		
		3	5.100x5.220	[illegible]	[illegible]	[illegible]	[illegible]		
	95 C	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
27.5 ชม. 31/12/2543	มาตรฐาน	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	Autogenous	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	75 C	1	[illegible]	[illegible]	[illegible]	4,450.00	[illegible]	[illegible]	
		2	[illegible]	25.7964	[illegible]	[illegible]	[illegible]		
		3	5.100x5.080	25.9080	[illegible]	[illegible]	[illegible]		
	95 C	1	5.050x5.090	25.7045	[illegible]	[illegible]	[illegible]	[illegible]	
		2	5.060x5.070	25.6542	[illegible]	[illegible]	[illegible]		
		3	5.050x5.070	[illegible]	[illegible]	[illegible]	[illegible]		
7 วัน 6/1/2544	มาตรฐาน	1	5.100x5.100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		3	5.000x5.180	[illegible]	[illegible]	[illegible]	[illegible]		
28 วัน 27/1/2544	มาตรฐาน	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
91 วัน 31/3/2544	มาตรฐาน	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		3	[illegible]	[illegible]	[illegible]	5,350.00	[illegible]		

ตาราง ข 11 ผลการทดลองกำลังอัดของมอร์ตาร์ซีเมนต์แทนที่ซีเมนต์ด้วย Flyash 40% จากระยอง W/B=0.6

เวลา	ชนิดการบ่ม	ตัวอย่าง	ขนาด	พื้นที่(cm^2)	น้ำหนัก(g)	Load(kg)	Stress(ksc)	ress เฉลี่ย(ks	หมายเหตุ
		1	4.980x4.970	24.7506	284.26	25.00	1.01		ถอดจากแบบก้อ
	มาตรฐาน	2	5.000x5.110	25.5500	287.50	50.00	1.96	1.53	ตัวอย่างยังคงม
		3	5.030x4.900	24.6470	291.12	40.00	1.62		ลักษณะเยิ้ม
		1	5.010x4.960	24.8496	288.95	45.00	1.81		ถอดจากแบบก้อ
	Autogenous	2	5.180x4.980	25.7964	294.47	55.00	2.13	1.90	ตัวอย่างยังคงม
3.5 ชม.		3	5.190x4.940	25.6386	289.14	45.00	1.76		ลักษณะเยิ้ม
30/12/2543		1	5.020x5.160	25.9032	290.86	1,485.00	57.33		น้ำเข้าไปในถุง
13:15	75 C	2	5.210x4.950	25.7895	290.77	1,500.00	58.16	57.64	พลาสติก
		3	5.000x5.120	25.6000	290.65	1,470.00	57.42		
		1	4.980x5.300	26.3940	291.84	3,125.00	118.40		
	95 C	2	5.180x5.000	25.9000	291.37	3,100.00	119.69	119.04	
		3	5.040x5.200	26.2080	292.45	2,075.00	79.17	ไม่คิดก้อน3	
		1	5.040x4.940	24.8976	292.30	2,425.00	97.40		
	มาตรฐาน	2	5.060x4.980	25.1988	295.92	2,125.00	84.33	91.00	
		3	5.020x5.020	25.2004	289.94	2,300.00	91.27		
		1	5.080x5.060	25.7048	304.05	2,225.00	86.56		
	Autogenous	2	5.020x5.030	25.2506	294.42	1,950.00	77.23	90.93	
27.5 ชม.		3	4.960x5.040	24.9984	293.54	2,725.00	109.01		
31/12/2543		1	4.970x5.010	24.8997	281.76	3,275.00	131.53		
	75 C	2	4.950x4.960	24.5520	284.24	3,575.00	145.61	145.56	
		3	4.980x4.940	24.6012	279.89	3,925.00	159.55		
		1	5.030x5.030	25.3009	282.68	4,625.00	182.80		
	95 C	2	5.020x5.030	25.2506	285.10	3,775.00	149.50	178.93	
		3	5.010x5.100	25.5510	286.83	5,225.00	204.49		
7 วัน		1	4.979x5.040	25.0942	294.41	5,025.00	200.25		
6/1/2544	มาตรฐาน	2	5.050x5.050	25.5025	292.97	4,875.00	191.16	189.80	
		3	4.960x5.040	24.9984	291.16	4,450.00	178.01		
28 วัน		1	5.060x5.060	25.6036	300.49	7,500.00	292.93		
27/1/2544	มาตรฐาน	2	5.110x5.150	26.3165	294.01	7,350.00	279.29	294.06	
		3	5.100x5.140	26.2140	294.87	8,125.00	309.95		
91 วัน		1	5.100x5.090	25.9590	291.93	6,675.00	257.14		กดจริงวันที่
30/3/2544	มาตรฐาน	2	5.090x5.150	26.2135	298.04	8,590.00	327.69	292.41	4/4/2544
		3	5.100x5.060	25.8060	291.90	6,175.00	239.29	ไม่คิดก้อน3	

ตาราง ข 12 ผลการทดลองกำลังอัดของมอร์ตาร์แทนที่ซีเมนต์ด้วย Flyash 60% จากราชบุรี W/B=0.5

เวลา	ชนิดการบ่ม	ตัวอย่าง	ขนาด	พื้นที่(cm^2)	น้ำหนัก(g)	Load(kg)	Stress(ksc)	ress เฉลี่ย(ks	หมายเหตุ
		1	5.030x5.040	25.3512	290.22	110.00	4.34		รูพรุนด้านข้าง
	มาตรฐาน	2	5.020x5.050	25.3510	290.22	130.00	5.13	4.53	รูพรุนด้านข้าง
		3	5.040x5.050	25.4520	289.43	105.00	4.13		
		1	5.000x5.030	25.1500	264.40	75.00	2.98		
	Autogenous	2	4.980x5.160	25.6968	269.68	60.00	2.33	3.04	
3.5 ชม.		3	4.970x5.040	25.0488	274.66	95.00	3.79		
5/1/2544		1	5.030x5.040	25.3512	267.65	1,175.00	46.35		รูพรุนด้านข้าง
12:00	75 C	2	5.000x5.030	25.1500	278.69	1,665.00	66.20	61.38	
		3	5.050x5.020	25.3510	279.64	1,815.00	71.59		
		1	5.000x5.200	26.0000	292.31	3,800.00	146.15		
	95 C	2	5.000x5.180	25.9000	287.53	3,075.00	118.73	132.39	
		3	5.000x5.140	25.7000	278.68	3,400.00	132.30		มีร่องด้านข้าง
		1	5.010x4.980	24.9498	287.50	2,150.00	86.17		
	มาตรฐาน	2	5.080x5.160	26.2128	287.00	1,995.00	76.11	81.71	
		3	5.110x5.150	26.3165	289.50	2,180.00	82.84		
		1	5.040x5.130	25.8552	260.50	1,205.00	46.61		มีรูพรุนด้*

ภาคผนวก ค

ข้อมูลการทดลองคอนกรีต

ตารางที่ ค1 ค่าเฉลี่ยของอัตราส่วนกำลังอัดของคอนกรีตในภาวะการบ่มเร่งต่อกำลังอัดที่อายุ 28และ 56 วัน (w/b0.40, 0.50,0.60)

	ตัวอย่างที่		avg	avg	faa/f28	facc/f56	faa/f28	facc/f56
w/b			f28	f56	75prompt	95prompt	75after	95after
0.4	1	0	591	610	0.308816	0.383959	0.517359	0.508677
0.4	2	0	591	610	0.409679	0.398128	0.511713	0.491017
0.4	3	0	591	610	0.359574	0.414197	0.509172	0.491661
0.4	4	0	591	610	0.34647	0.470334	0.454895	0.510277
0.4	1	20	478	614	0.370363	0.340662	0.363858	0.340812
0.4	2	20	478	614	0.419979	0.375473	0.418929	0.404095
0.4	3	20	478	614	0.375335	0.370817	0.417738	0.430443
0.4	4	20	478	614	0.405396	0.353914	0.429572	0.445071
0.4	1	30	462	489	0.279712	0.422402	0.395839	0.380284
0.4	2	30	462	489	0.329218	0.379666	0.37915	0.404484
0.4	3	30	462	489	0.326799	0.37381	0.403896	0.39908
0.4	4	30	462	489	0.313066	0.377589	0.384074	0.42464
0.4	1	40	407	444	0.282492	0.413499	0.325	0.334512
0.4	2	40	407	444	0.244679	0.390089	0.35069	0.437122
0.4	3	40	407	444	0.264618	0.372824	0.337158	0.404008
0.4	4	40	407	444	0.276555	0.42594	0.375313	0.356895
0.4	1	50	384	426	0.19256	0.366839	0.276621	0.319307
0.4	2	50	384	426	0.204776	0.326535	0.263454	0.353506
0.4	3	50	384	426	0.205023	0.365499	0.267493	0.345283
0.4	4	50	384	426	0.221738	0.352223	0.264377	0.329653
0.5	1	0	440	476	0.398095	0.446621	0.444121	0.402773
0.5	2	0	440	476	0.406769	0.458754	0.456035	0.393435
0.5	3	0	440	476	0.498176	0.451052	0.443076	0.423811
0.5	4	0	440	476	0.476864	0.500112	0.455211	0.43566
0.5	1	20	403	482	0.317444	0.322298	0.289384	0.300853
0.5	2	20	403	482	0.354476	0.361007	0.286579	0.30403
0.5	3	20	403	482	0.329057	0.325536	0.32376	0.294857
0.5	4	20	403	482	0.346582	0.342902	0.305653	0.297174

ตารางที่ ค1 ค่าเฉลี่ยของอัตราส่วนกำลังอัดของคอนกรีตในภาวะการบ่มเร่งต่อกำลังอัดที่อายุ 28และ 56 วัน (ต่อ)

w/b	ตัวอย่างที่		avg f28	avg f56	faa/f28 75prompt	facc/f56 95prompt	faa/f28 75after	facc/f56 95after
0.5	1	30	448		0.21209		0.23777	
0.5	2	30	448		0.212594		0.254013	
0.5	3	30	448		0.22176		0.232421	
0.5	4	30	448		0.208323		0.260733	
0.5	1	40	375	434	0.273219	0.33833	0.301066	0.312276
0.5	2	40	375	434	0.263228	0.315045	0.326062	0.333715
0.5	3	40	375	434	0.232901	0.333029	0.316933	0.294789
0.5	4	40	375	434	0.272957	0.332968	0.299432	0.299334
0.5	1	50	299	407	0.204766	0.284561	0.261566	0.293091
0.5	2	50	299	407	0.190724	0.303624	0.26217	0.264892
0.5	3	50	299	407	0.187293	0.276496	0.256653	0.273373
0.5	4	50	299	407	0.185509	0.310074	0.287667	0.270218
0.6	1	0	392		0.322542		0.421841	
0.6	2	0	392		0.34904		0.414923	
0.6	3	0	392		0.325533		0.439297	
0.6	4	0	392		0.345798		0.40331	
0.6	1	20	356		0.246603		0.325593	
0.6	2	20	356		0.251583		0.315852	
0.6	3	20	356		0.239713		0.327655	
0.6	4	20	356		0.248248		0.317531	
0.6	1	30	274		0.21434		0.29916	
0.6	2	30	274		0.209561		0.306104	
0.6	3	30	274		0.196852		0.295003	
0.6	4	30	274		0.208313		0.292883	
0.6	1	40	282		0.221641		0.255418	
0.6	2	40	282		0.227797		0.28717	
0.6	3	40	282		0.199283		0.25827	
0.6	4	40			0.21469		0.239905	

ตารางที่ ค1 ค่าเฉลี่ยของอัตราส่วนกำลังอัดของคอนกรีตในภาวะการบ่มเร่งต่อกำลังอัดที่อายุ 28และ 56 วัน(ต่อ)

	ตัวอย่างที่		avg	avg	faa/f28	facc/f56	faa/f28	facc/f56
w/b			f28	f56	75prompt	95prompt	75after	95after
0.6	1	50	234		0.160412		0.225851	
0.6	2	50	234		0.174428		0.232583	
0.6	3	50	234		0.171568		0.216065	
0.6	4	50	234		0.162209		0.225652	

ตารางที่ ค2 ค่าเฉลี่ยของอัตราส่วนกำลังอัดของคอนกรีตในภาวะการบ่มเร่งต่อกำลังอัดที่อายุ 28และ 56

- **วัน(w/b0.50)**

0.5	1	0	440.1743	475.867	0.398095	0.446621	0.444121	0.402773
0.5	2	0	440.1743	475.867	0.406769	0.458754	0.456035	0.393435
0.5	3	0	440.1743	475.867	0.498176	0.451052	0.443076	0.423811
0.5	4	0	440.1743	475.867	0.476864	0.500112	0.455211	0.43566
0.5	1	20	402.7238	482.2394	0.317444	0.322298	0.289384	0.300853
0.5	2	20	402.7238	482.2394	0.354476	0.361007	0.286579	0.30403
0.5	3	20	402.7238	482.2394	0.329057	0.325535	0.32376	0.294857
0.5	4	20	402.7238	482.2394	0.346582	0.342902	0.305653	0.297174
0.5	1	30	447.9098		0.21209		0.23777	
0.5	2	30	447.9098		0.212594		0.254013	
0.5	3	30	447.9098		0.22176		0.232421	
0.5	4	30	447.9098		0.208323		0.260733	
0.5	1	40	374.7514	433.6588	0.273219	0.33833	0.301066	0.312276
0.5	2	40	374.7514	433.6588	0.263228	0.315045	0.326062	0.333715
0.5	3	40	374.7514	433.6588	0.232901	0.333029	0.316933	0.294789
0.5	4	40	374.7514	433.6588	0.272957	0.332968	0.299432	0.299334
0.5	1	50	299.1378	407.3711	0.204766	0.284561	0.261566	0.293091
0.5	2	50	299.1378	407.3711	0.190724	0.303624	0.26217	0.264892
0.5	3	50	299.1378	407.3711	0.187293	0.276496	0.256653	0.273373
0.5	4	50	299.1378	407.3711	0.185509	0.310074	0.287667	0.270218

ตารางที่ ค3 ค่าเฉลี่ยของอัตราส่วนกำลังอัดของคอนกรีตในภาวะการบ่มเร่งต่อกำลังอัดที่อายุ 28และ 56 วัน(w/b0.60)

0.6	1	0	391.8905	0.322542	0.421841
0.6	2	0	391.8905	0.34904	0.414923
0.6	3	0	391.8905	0.325533	0.439297
0.6	4	0	391.8905	0.345798	0.40331
0.6	1	20	355.8313	0.246603	0.325593
0.6	2	20	355.8313	0.251583	0.315852
0.6	3	20	355.8313	0.239713	0.327655
0.6	4	20	355.8313	0.248248	0.317531
0.6	1	30	274.2123	0.21434	0.29916
0.6	2	30	274.2123	0.209561	0.306104
0.6	3	30	274.2123	0.196852	0.295003
0.6	4	30	274.2123	0.208313	0.292883
0.6	1	40	281.9444	0.221641	0.255418
0.6	2	40	281.9444	0.227797	0.28717
0.6	3	40	281.9444	0.199283	0.25827
0.6	4	40		0.21469	0.239905
0.6	1	50	233.9402	0.160412	0.225851
0.6	2	50	233.9402	0.174428	0.232583
0.6	3	50	233.9402	0.171568	0.216065
0.6	4	50	233.9402	0.162209	0.225652

ตาราง ค4 อัตราส่วนของกำลังอัดจากการบ่มเร่งทันที ต่อ จากการบ่มเร่งปกติที่ 28 และ 56 วัน

w/b	ตัวอย่างที่		faa/f28	facc/f56	faa/f28	facc/f56
0.4	1	0	0.3088155	0.38395854	0.51735912	0.50867674
0.4	2	0	0.40967895	0.39812789	0.51171257	0.49101662
0.4	3	0	0.35957415	0.41419675	0.50917163	0.49166132
0.4	4	0	0.34646956	0.47033441	0.45489541	0.51027655
0.4	1	20	0.37036342	0.34066244	0.36385781	0.34081196
0.4	2	20	0.41997857	0.37547282	0.41892869	0.40409518
0.4	3	20	0.37533498	0.37081741	0.41773756	0.43044319
0.4	4	20	0.40539637	0.35391442	0.42957163	0.44507058
0.4	1	30	0.27971249	0.42240223	0.39583947	0.38028353
0.4	2	30	0.32921769	0.37966594	0.37915014	0.40448408
0.4	3	30	0.32679885	0.37381026	0.40389617	0.39907968
0.4	4	30	0.31306574	0.37758943	0.38407417	0.42463995
0.4	1	40	0.2824918	0.41349922	0.32499976	0.33451168
0.4	2	40	0.24467858	0.39008916	0.35069023	0.43712238
0.4	3	40	0.26461828	0.37282411	0.33715849	0.40400828
0.4	4	40	0.27655471	0.42594008	0.37531315	0.35689503
0.4	1	50	0.19256022	0.36683861	0.2766213	0.31930737
0.4	2	50	0.20477613	0.32653509	0.26345367	0.35350587
0.4	3	50	0.20502277	0.36549856	0.26749306	0.34528338
0.4	4	50	0.22173759	0.35222261	0.26437722	0.32965286
0.5	1	0	0.39809546	0.4466207	0.4441208	0.4027733
0.5	2	0	0.40676914	0.45875447	0.45603485	0.39343536
0.5	3	0	0.49817572	0.4510515	0.44307568	0.42381093
0.5	4	0	0.47686354	0.50011175	0.4552107	0.43566016
0.5	1	20	0.31744403	0.32229793	0.28938432	0.30085272
0.5	2	20	0.35447608	0.36100735	0.28657907	0.30402965
0.5	3	20	0.32905705	0.32553606	0.32376021	0.29485655
0.5	4	20	0.34658236	0.34290198	0.30565287	0.29717401
0.5	1	30	0.21209008		0.23776956	
0.5	2	30	0.21259406		0.25401261	
0.5	3	30	0.22175995		0.23242057	
0.5	4	30	0.20832267		0.26073281	

ตาราง ค4 อัตราส่วนของกำลังอัดจากการบ่มเร่งทันที ต่อ จากการบ่มเร่งปกติที่ 28 และ 56 วัน (ต่อ)

w/b	ตัวอย่างที่		faa/f28	facc/f56	faa/f28	facc/f56
0.5	1	40	0.2732187	0.33832973	0.30106632	0.3122756
0.5	2	40	0.26322826	0.31504477	0.3260622	0.33371467
0.5	3	40	0.23290107	0.33302872	0.31693278	0.29478924
0.5	4	40	0.27295654	0.33296841	0.2994319	0.29933358
0.5	1	50	0.20476568	0.28456105	0.26156627	0.29309065
0.5	2	50	0.19072358	0.30362389	0.26217025	0.26489151
0.5	3	50	0.18729285	0.27649599	0.25665327	0.27337349
0.5	4	50	0.18550912	0.31007434	0.28766668	0.27021775
0.6	1	0	0.32254194		0.42184071	
0.6	2	0	0.34903987		0.41492319	
0.6	3	0	0.32553285		0.43929709	
0.6	4	0	0.34579843		0.40330956	
0.6	1	20	0.24660263		0.32559278	
0.6	2	20	0.25158302		0.31585178	
0.6	3	20	0.23971335		0.32765548	
0.6	4	20	0.24824762		0.31753076	
0.6	1	30	0.21433998		0.29915975	
0.6	2	30	0.20956143		0.30610424	
0.6	3	30	0.1968522		0.29500315	
0.6	4	30	0.20831291		0.29288253	
0.6	1	40	0.22164105		0.25541824	
0.6	2	40	0.22779741		0.28716972	
0.6	3	40	0.19928325		0.25827047	
0.6	4	40	0.21468974		0.2399047	
0.6	1	50	0.16041231		0.22585063	
0.6	2	50	0.17442765		0.23258323	
0.6	3	50	0.1715678		0.2160652	
0.6	4	50	0.1622095		0.2256523	

ภาคผนวก จ

ผลลัพธ์จากโครงการวิจัย

2. ผลงานตีพิมพ์

2. 2. Sujjavanich Suvimol and Suwanvitaya Prasert, Effect of High Temperature on Strength Properties of Flyash Cement Mortar, Proceeding in The Third Regional Symposium of Infrastructure Development 4 - 7 ธ.ค. 2543 ที่Tokyo Institute of Technology ประเทศญี่ปุ่น

2. 2. Sujjavanich Suvimol and Suwanvitaya Prasert, : Effect of Moderate Calcium Oxide Flyash on Concrete Permeability in Tropical Climate, Proceeding in Third International Conference on Concrete under Severe Conditions: Environment and Loading , 18-20 มิย. 2544 ที่ Vancouver ประเทศCanada

2. 3. Sujjavanich Suvimol and Suwanvitaya Prasert, Effect of accelerated curing conditions on microstructure and strength of fly ash cement mortar, Proceeding in The Fourth Regional Symposium of Infrastructure Development 3- 5 เมย. 2546 ที่ กรุงเทพ ประเทศไทย

2. 4 Chatupol Roekattakarn, Suvimol Sujjavanich and Tanakorn Pheeraphan, Comparison of the later-age compressive strength prediction of fly ash concrete using different heat sources, Proceeding in The Fourth Regional Symposium of Infrastructure Development 3- 5 เมย. 2546 ที่กรุงเทพ ประเทศไทย

2. การนำผลงานวิจัยไปใช้ประโยชน์

ผลงานวิจัยอาจใช้เป็นแนวทางพิจารณาหาวิธีการทดสอบการเร่งกำลังที่เหมาะสมของคอนกรีตผสมเถ้าลอยเพื่อใช้เป็นวิธีตรวจสอบและควบคุมคุณภาพในระยะเวลาสั้นสำหรับงานก่อสร้าง

ภาคผนวก ฉ

บทความจากโครงการวิจัย

EFFECT OF HIGH TEMPERATURE ON STRENGTH PROPERTIES OF FLYASH CEMENT MORTAR

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ABSTRACT

Significant increase in volume of flyash concrete use in Thailand raises concern in quality control and means for corrective measure during construction. This paper proposed an adaptive approach of using high temperature for strength estimation of flyash cement mortar.

Compressive strength of mortars cured at 75 and 95 °C for a short duration after casting were studied, compared to 1, 7 and 28 day strength of normal curing method. The cement replacement by local flyash at 0, 20, 30 and 40% were studied. Both curing temperatures were found to strongly influence strength development of flyash cement mortar. A slight difference in accelerated strength was observed. Repeatability to a certain level was also reported. However, the moisture condition during heat acceleration significantly reduced the strength gain. Results of the study provide information for the further study of heat acceleration for long term strength prediction of flyash concrete.

Keyword: flyash, heat

INTRODUCTION

Local flyash has been introduced in Thai concrete industry only a few years ago. Mae-Moh Electrical Power Plant in the north, currently outputting 9,000 tons of fly ash daily, is the major local producer in Thailand. The uniformity of this by-product has been reported (1). Even though Mae-Moh flyash is produced from burning Lignite, its chemical compositions lie between class C and F, according to ASTM classification (2). The calcium oxide content is moderate, 7-13% approximately.

Recently, volume uses of flyash concrete are significantly increasing. This reasons from the low cost of local flyash, its potential for partial cement replacement uses, and the increasing concern to environment and management problems. The large amount of replaced flyash significantly affect concrete performances, both in fresh and hardened state.

The delayed pozzolanic reaction required the longer period for property's development than normal concrete. This raise concern in quality control and means for corrective measure during construction. The common strength at 56 or 91 days is unpractical for field adjusting or for quality control purpose. Therefore, the need to predict the potential characteristics of early age concrete is essential for flyash concrete uses.

Curing temperatures strongly influenced cement hydration in normal concrete. Utilizing heat to accelerate strength development is widely accepted (3,4). The American and British standards allow slight different temperatures of warm water and boiling water-curing condition to accelerate early strength for quality control purpose.

The effect of high temperature on both hydration and pozzolanic reaction in flyash concrete is widely recognized (5,6). However, the effect of high curing temperature on strength of 1-day concrete samples is moderate (7). At present, only a few information concerning this issue is available (8,9). Therefore, this paper investigates the effect of high temperature curing on strength properties of flyash mortar. This is a part of the research which propose an adaptive approach of using high temperature for strength estimation of flyash concrete.

RESEARCH SIGNIFICANCE

The study provides information on the effect of high curing temperature on strength properties of flyash cement mortar, using moderate-calcium local flyash. The information is essential for the further study to predict long term strength properties of flyash concrete. This is expected to benefit the quality control application for flyash concrete construction.

MATERIALS AND SPECIMEN PREPARATION

The local lignite flyash which the chemical compositions and physical properties are shown in Table 1 was used in this study. Two inches cube mortar samples with flyash partially replaced cement at three levels, i.e. 20 %, 30% and 40% were cured under two different temperatures, 75 and 95 °C in waterbath and under normal condition. Under 95 °C condition, two methods, boiling and steam curing were comparatively studied. Since the accelerated cure was conducted at the very early age, a special care was provided to prevent direct water contact. Special plastic bags and accessories were used for this purpose.

Strength development curve under 95 °C curing was firstly established to study the effect of curing duration. Finally, the curing duration 3 ½ hours after casting were adopted for further study for both curing temperatures. This is similar to the duration suggested by ASTM standard.

Coarse river sand and Portland Cement type I were used in this study. The cement to sand ratio was 1:3 and water to binder ratios was 0.4 to 0.5 respectively.

The compressive strength test was conducted in half an hour after removing specimens from the waterbath. The results were compared to strength of the normal curing condition at 1, 7 and 28 days.

Table 1 Chemical compositions and physical properties of Mae-Moh flyash and ASTM class flyash

Description	Maemoh flyash	Class C ASTM	Class F ASTM
$SiO_2+Al_2O_3+Fe_2O_3$ (Min.%)	86.2	50.0	70.0
SO_3 (Max.%)	0.95	5.0	5.0125
CaO (%)	6.0.	>10.0	<10.0
LOI (%)	0.33	6.0	6.0
Free lime	0.21		
Specific gravity	1.63		
Bulk density (g/cm^3)	0.843		
Specific surface area (cm^2/g)	3122		
Mean diameter(μm)	108		
Percent retained on 45μm sieve	53.3		

TEST RESULTS AND DISCUSSION

Compressive strength of mortars cured at 75 and 95 °C for a short duration after casting were studied, compared to 28 day strength of normal curing method.

95 °C strength development curve

The strength development curve of cement mortar with water binder ratio 0.4 and 20% flyash as cement replacement is shown in Figure 1. The compressive strength tests were conducted at 2 ½, 3 ½, 5, 7, 6 and 8 hours cured under 95 °C curing condition. Increasing strength as the curing duration increased indicates the strong effect of high temperature curing duration. However, this effect is less as water to binder ratio increases.

The curing time 3 ½ hr. was chosen through the study. This reasons from the compared strength at this stage are more uniform than of the other ages, the similarity to ASTM recommendation and the consideration of the convenience to finish the test during the working hour.

The results also show an increasing strength of samples cured at 95 °C for 8 hours and left for air cured until test at 24hours, compared to of the normal cured at the same age (1.59 times). However when compared to strength of the same accelerated curing duration, the observed slight increasing strength indicates the little continued effect of high temperature.

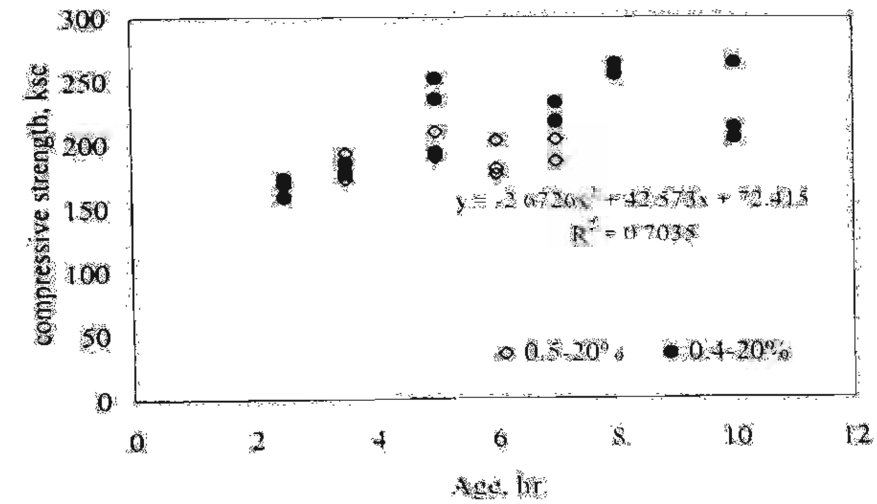

Figure 1 The relationship between accelerated strength at 95 °C and time

Effect of curing temperature

For normal cement mortar, the effect of difference in curing temperature appears to increase for low water binder ratio mixes. Accelerated strength under 75°C condition is 4% and 12.5% less than of 95 °C for w/b 0.5 and 0.4 respectively. However, mixes with flyash reveal the effect from temperature level in the higher degree. The effect also increases as percent replacement increases (5 %to 44%). The water binder ratio is also found to influence the accelerated strength. The effect is also increased as the ratio decreases. The effect of temperature level on accelerated strength is shown in Figure 2, regardless to water binder ratio and flyash content.

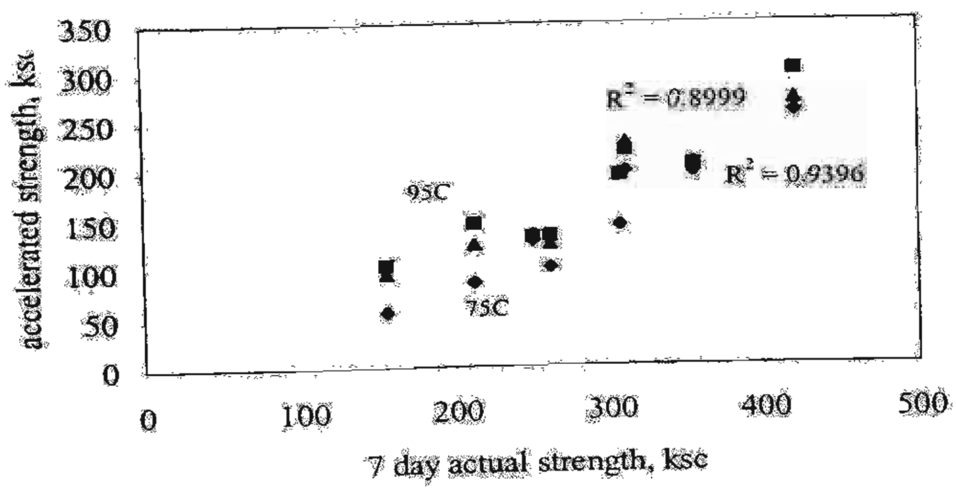

Figure 2 Effect of temperature level on accelerated strength

Comparing the results of boiling and steam curing under 95 °C condition, the sample's mean strength appears to statistically differ insignificant. These are consistent for both normal and flyash cement mortars almost all mixes. Only one mix (w/b 0.5-20% flyash) shows the difference.

Accelerated and normal curing strength Relationship

To compare the strength development, the ratio of accelerated strength at 75°C and 95 °C to strength at 1 and 7 day and percent replacement of flyash is plotted in Figure 3. Compared to cement mortar, At the early age, the strength ratio of cement mortar (not show in Figure) almost close to one for both temperatures. The strength ratio for flyash mortar is more subjective to both temperature level and flyash content. However, the relationship of strength at 28 days can not be established at this stage due to the limited data.

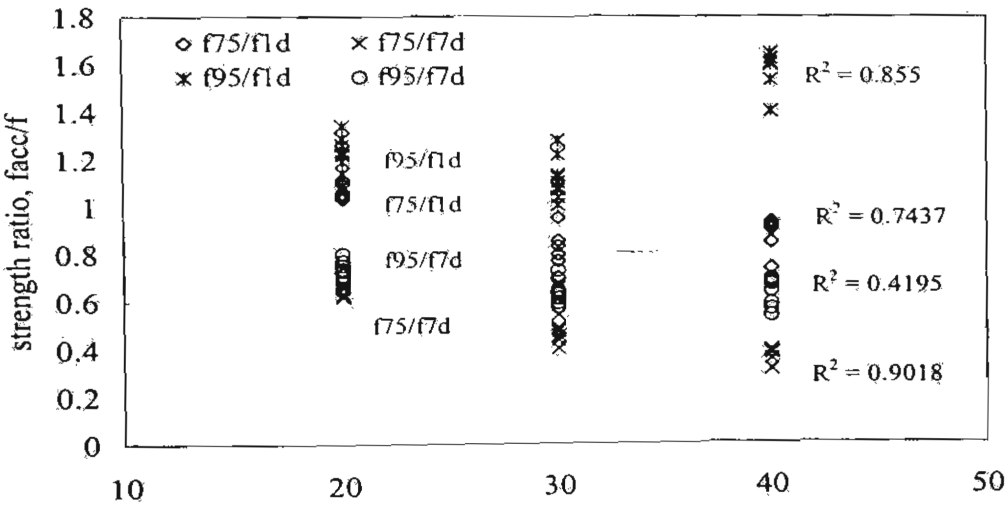

Figure 3 Relationship of strength ratios at different age and flyash content

When only compressive strength is considered, the accelerated strength at 95 °C and the available 28 day strength is plotted as in Figure 4. The relationship is in a polynomial form as

$$y = -0.0171x2 + 7.5478x - 414.16 \quad (R^2 = 0.6416)$$

Since the high temperature curing in this study is performed after casting, the moisture control strongly affects the accelerated strength. The strength significantly decreases if there is water leaks in to the mold, especially during the early cure.

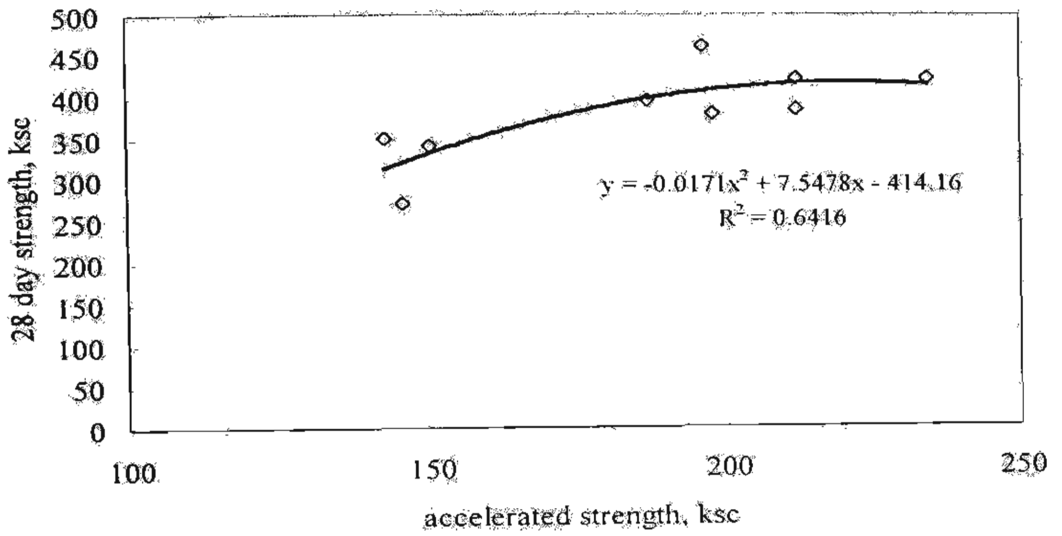

Figure 4 Relationship between accelerated strength at 95 °C and 28 day strength

CONCLUSIONS

High curing temperatures strongly influence strength development of flyash cement mortar. The curing duration 3 ½ hours after casting is proposed for practicing, based on data consistence and ease of work. Compared to the ordinary mortar, the effect of temperature level on the accelerated strength of flyash mortar is more essential.

The strength under 95°C curing is always significantly higher than of 75°C curing, regardless to the used method. The statistical analysis of most data from both boiling and steam curing conditions indicated an insignificant difference. At the low temperature, strength decreasing as flyash content increased is more pronounced. The specimen preparation and care during heat acceleration affect the strength gain.

Accelerated strength to strength at 7 days ratios lie between 0.4-0.5. The relationship between accelerated and actual strength appears to be a polynomial equation. The predicted 28 day strength equation, when x is an accelerated strength and y is a predicted strength, is

$$y = -0.0171x^2 + 7.5478x - 414.16 \quad (R^2 = 0.6416)$$

Results of this study indicate the repeatability to a certain level. These provide information for the further study of heat acceleration for long term strength prediction of flyash concrete.

Acknowledgements

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TITLE: Effect of Moderate Calcium Oxide Flyash on Concrete Permeability in Tropical Climate

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Abstract

Significant increase in the use of local flyash in Thailand's concrete industry raises concern in durability and long term performance. This paper reported changes in chloride permeability of moderate calcium oxide flyash concrete in tropical climate. Cement replacement by plant-classified flyash at 0, 20, 30 and 40% were studied. Tests for Rapid Chloride Permeability and compressive strength were conducted at the age of 150 days after 28 day curing at 28 °C and 40 °C.

It was found that both curing temperature and particle size strongly influenced the permeability. Significant reductions in permeability were observed, particularly at higher temperature as well as from finest particle size . Flyash concrete showed better improvement compared to both conventional and silica fume concrete of similar strength levels and curing conditions. Concrete with 20% flyash yielded the best result for both temperatures. The study indicated possible use of local flyash in tropical marine environment.

Keyword: flyash, chloride permeability, tropical climate

1. Introduction

Thailand, located in Southeast Asia, has typical tropical climate, with average daily temperature between 27-30° C and the high humidity. These result in the rapid deterioration of concrete structures. Corrosion and concrete deterioration are commonly reported especially in the coastal area in the south and the east. There are at present coordinated efforts at the improvement in the codes of practice in the construction industry to bring about long service life of structures.

Mineral admixtures, especially silica fume, have been used in Thailand for about a decade. Flyash, on the other hand, has only been introduced in concrete industry a few years ago. While silica fume is commercially imported, flyash is locally produced from electricity generation. Mae-Moh Electrical Power Plant in the north, currently outputting 9,000 tons of fly ash daily, is the major local producer in Thailand. The uniformity of this by-product has been reported (1). Even though Mae-Moh flyash is produced from burning Lignite, its chemical compositions lie between class C and F, according to ASTM classification (2). The calcium oxide content is moderate, 7-13% approximately.

Recently, uses of local flyash in Thai concrete industry are significantly increasing. This results from the low cost, previous studies of its potential as cementitious material, and the increasing attention to environment and management problems. The increasing use raises concern in durability and long term performance. However, there is little available data related to these issues for local flyash concrete as well as for silica fume concrete, especially in local environment. Some available information from western countries may not be readily accepted in lieu of the climatic differences. There is, therefore, a need for the study of material properties and performances under the actual conditions.

The advantages of mineral admixtures on concrete durability have been recognized. A significant permeability reduction, resulting from microstructure improvement and pore system modification, has been reported, both for flyash and silica fume concrete (3,4). High curing temperature (23-38°C) improved chloride penetration resistance as well as strength development (5). The better performance over normal concrete at 28 days age, of silica fume concrete and concrete incorporating class F flyash was reported. However, at the lower temperature (20°C) the chloride permeability of flyash concrete was reportedly lower than that of concrete without flyash (6).

This paper reported changes in chloride permeability of moderate calcium oxide flyash concrete under tropical climate. The results are compared with conventional and silica fume concrete under the same curing conditions.

2. Research Significance

This comparative study provides information on chloride permeability of concrete incorporating flyash and silica fume under tropical climate. This is essential in the prediction of structural performance in moderately hot and humid condition. The results are expected to be used as guidance for design and construction practice to extend service life of structures.

3. Materials and Specimen Preparations

In this report, properties of flyash concrete was compared with those of conventional and silica fume concrete. Plant-classified particle size flyash partially replaced cement at three levels, ie 20 %, 30% and 40%. The coarse and fine particles were separated by their own weight in different hoppers (flyash A and flyash C). The chemical compositions and physical properties of flyash used are shown in Table 1.

For silica fume concrete, cement was partially replaced at three levels, ie 5, 10 and 15% by weight. The specific gravity and bulk density of silica fume were 2.19 and 600 kg./m^3 respectively. One and two percent of Napthalene Formaldehyde Sulfonate superplasticizer were used with silica fume during mixing.

Table 1 Chemical compositions and physical properties of Mae-Moh flyash and ASTM class flyash

Description	Coarse flyash (A)	fine flyash (C)	Class C ASTM	Class F ASTM
$SiO_2+Al_2O_3+Fe_2O_3$ (Min.%)	86.2	71.5	50.0	70.0
SO_3(Max.%)	0.95	3.75	5.0	5.0
CaO (%)	6.0	14.2	>10.0	<10.0
LOI (%)	0.33	0.85	6.0	6.0
Free lime	0.21	0.24		
Specific gravity	1.63	2.58		
Bulk density (g/cm^3)	0.843	0.760		
Specific surface area (cm^2/g)	3122	7290		
Mean diameter(μm)	108	5		
Percent retained on 45μm sieve	53.3	1		

Aggregates in this study were crushed lime stone with maximum size of 1/2" and coarse river sand. The mix proportions, based on 28 days strength, are shown in Table 2.

Table 2 Mix proportions of concrete

W/B	Cement (kg.)	Sand (kg.)	Agg. (kg.)	Water (kg.)	Flyash (%)	Silica fume (%)	SP (%)	f_{c28day} MPa
0.4	480	714	950	205	0	0	0	58
0.5	480	592	950	250	0	0	0	45
0.35	500	729	950	175	0	0	1	61
0.35	500	729	950	175	0	0	2	71

Specimens, cast in 3 in. cubical mold for compressive strength test and 4 in. x8 in. cylindrical mold for Rapid Chloride Permeability test, were moist cured for 24 hours. The 3in.x3in.x3in. sample size was chosen to avoid variation between mixes due to the limited capacity of mixer. After demolding, two sets of specimens were water cured at room temperature and in 40°C curing controlled tank for 28 days. The 28°C and 40°C simulated the average and high temperature of tropical climate in Bangkok. All specimens for chloride test were continuously water cured at room temperature until the age of testing, 150 days. The cylindrical samples were cut and the 2 in. slices at the mid height were used for testing.

4. Test Results and Discussion

4.1 General strength properties

In this study, water cement ratio, amount of superplasticizer, and temperature affected compressive strength of normal concrete to different degrees. Reducing water cement ratio (from 0.5 to 0.4) resulted in increasing the strength by 27 percent. While increasing superplasticizer from 1 to 2% and increasing curing temperature from 28°C to 40°C increased the compressive strength by 17% and 3%, respectively.

Adding flyash and silica fume yielded a different result. An increasing strength is shown at the high temperature curing. However, particle size and percent replacement appeared to be significant factors. The comparison of compressive strength versus percentage of cement replacement of flyash and silica fume are shown in Figure 1.

Compared to the effect of coarse particle (Flyash A), fine particle of plant classified flyash (flyash C) is much more reactive at any age and any curing temperature. The strength of concrete incorporating 20% of flyash C is comparable to silica fume concrete. However, strength decreased as percentage of cement replacement increased, at all ages, for both flyash, both water binder ratios and both temperatures. For silica fume concrete, increasing silica fume up to 10% significantly increased strength. However, at 15% replacement the strength decreased. Similar trend is observed for both temperatures and superplasticizer levels. The dispersion effect of superplasticizer is clearly seen, especially at lower dosage of silica fume (5%) for both temperatures.

4.2Chloride penetration resistance

For normal concrete, the measured chloride permeability in term of charge passed significantly related to strength in a polynomial pattern (R^2=0.9999). The higher the strength, the lower the chloride permeability. The trend is shown by dotted line in Fig.2. However, the test results indicated the tendency of increasing permeability as the temperature increased. The studied concrete was classified in the range of medium to high, according to ASTM C1202.

Adding superplasticizer strongly affected concrete permeability. Compared to the same strength level, concrete with superplasticizer has lower permeability than normal concrete. A significant reduction in charge passed could be the result of the more uniform dispersion of cement particles, thus giving a denser and more uniform matrix. The influence of amount variation of superplasticizer and curing temperature in the studied range are apparently small. However, the results show the tendency of decreasing the chloride permeability of these concrete.

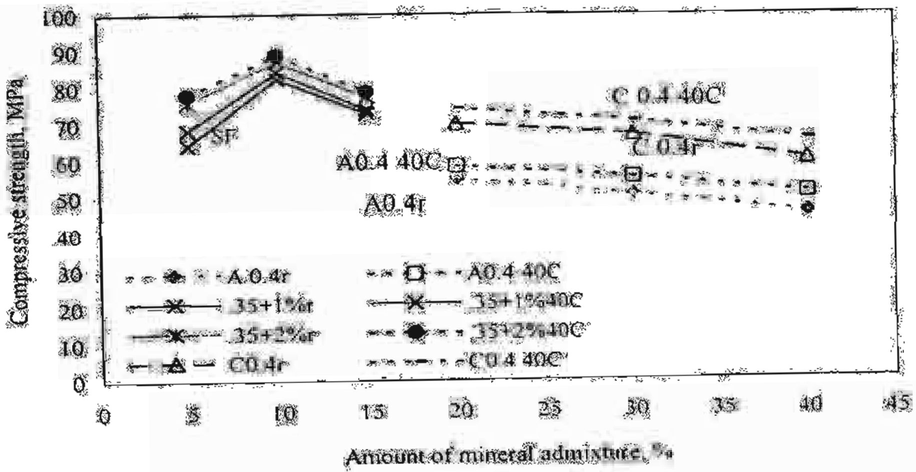

Fig.1 Relationship of strength and admixture content in different curing conditions

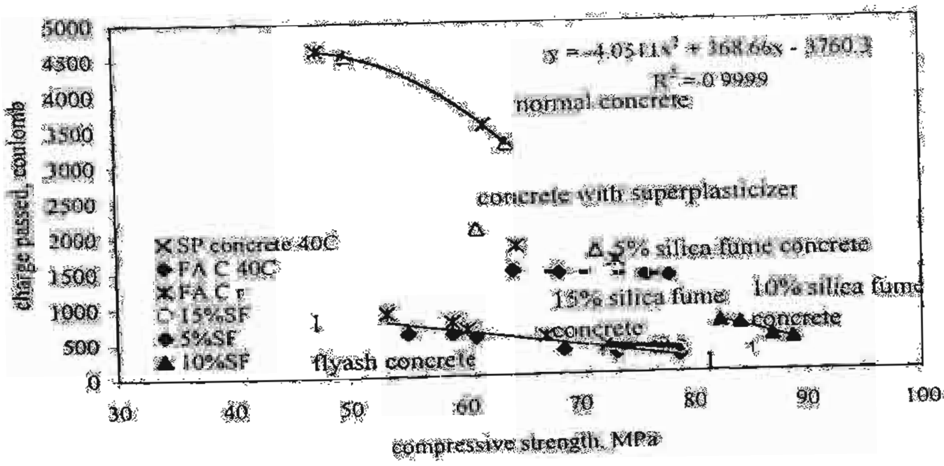

Fig.2 Relationship between strength and chloride permeability in terms of charge passed

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The reduction of the charge passed is even more pronounced for concrete with flyash and silica fume. The performance of the concrete with classified ash changed from moderate to low level. Flyash C yielded very low charge passed, comparable to, and in some cases better than, silica fume concrete. The trend is shown by line 1-1 in Fig.2. However, the charge passed increased for both fine and coarse flyash as cement replacement percentage, and water cement ratio increased. As temperature increased to 40°C, both flyash revealed a significant charge passed reduction.

These phenomena are slightly different for silica fume concrete. In Fig.3 as the percentage of silica fume increased, the chloride permeability dramatically decreased. Temperature in the studied range did not show as strong an effect on silica fume concrete as it did flyash concrete.

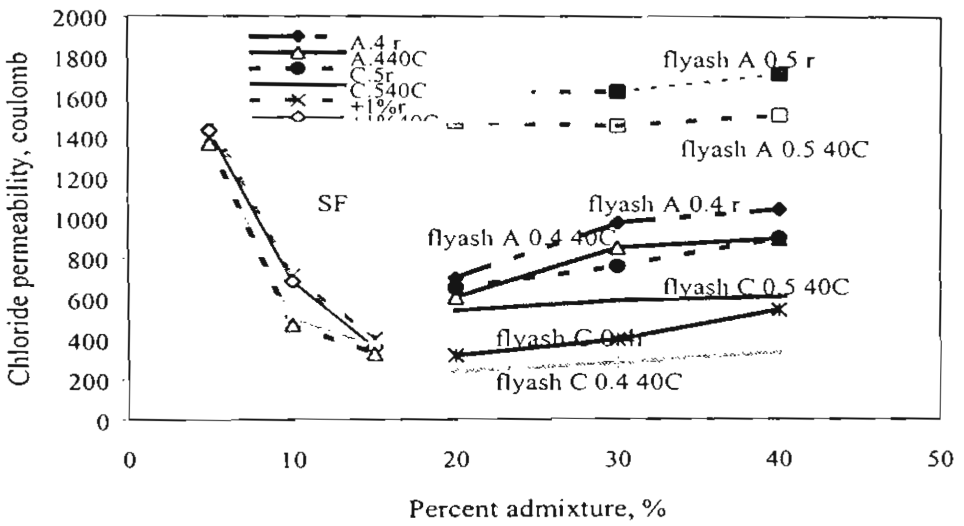

Fig. 3 Relationship of chloride permeability and amount of admixture

5. Conclusions

Mix proportion especially water binder ratio and admixture, and curing conditions are key factors that influence both strength and durability properties. In this study both curing temperature and particle size strongly influenced permeability. The smaller size of plant classified flyash is much more reactive than the coarser one.

Significant reductions in permeability were observed, particularly at higher temperature as well as from fine particle size . The permeability value in flyash concrete became very low, compared to the high and low levels of conventional and silica fume concrete of similar strength levels and curing conditions. Concrete with 20% flyash revealed the best result for both temperatures.

The smaller size of local flyash showed the potential as a substitute for silica fume, focusing on strength and chloride permeability. The study indicated the possible use of local flyash in tropical marine environment.

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EFFECT OF ACCELERATED CURING CONDITIONS ON MICROSTRUCTURE AND STRENGTH OF FLY ASH CEMENT MORTAR

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ABSTRACT

High temperature accelerates microstructure and strength development of fly ash concrete differently from normal concrete. This paper investigated the effect of high curing temperature and duration on microstructure and strength properties of mortar incorporating local fly ash. Compressive, tensile and flexural strength of mortars cured at 75 and 95°C promptly and after 24 hours casting were studied. The results were compared to 28-day strength of normal curing method. The replacement percentages of cement by fly ash were between 0 and 50%. Microstructure was studied on selected samples, using SEM and XRD Techniques. Calcium hydroxide contents were estimated from moisture losses from paste, at specified temperatures. The lower amount corresponding to 95°C curing temperature and 28 day normal cure implied an increase in C-S-H, compared to the one cured at 75°C. Concerning strength properties, both curing temperatures strongly influenced compressive strength. Compressive strength ratios of accelerated to 28-day normal cure were in the range of 0.25-0.65, depending on replacement percentage. However both tensile and flexural strength ratios appeared to be less sensitive to temperature, regardless of replacement percentage and curing duration. The strength under 95°C curing was always significantly higher than that under 75°C curing. The products from hydration and pozzolanic reaction, as well as some micro cracks were observed in 3.5 hours under high temperature curing regime. The curing duration of 3.5 hours after casting and curing temperatures of 75°C and 95°C were proposed for further study. Compared to ordinary mortar, the effect of temperature level on the accelerated strength of fly ash mortar was more significant.
KEYWORDS: fly ash, accelerated curing, strength, microstructure

INTRODUCTION

High temperature affects both microstructure and strength development of fly ash concrete as well as normal concrete. However, for fly ash-cement system, both cement hydration and pozzolanic reactions appear to react dependently and benefit each other. Higher reaction rate and 10% higher amount of hydrated C_3S at the age of one day, were reported in fly ash-cement paste, compared to that of the pure C_3S paste [1]. Also, high temperature from early curing decreases the length of dormant period in cement hydration and the early-established structure of hydrated product is a result. The porous and loose structure is widely recognized in normal concrete as a result of accelerated microstructure development [2]. This phenomenon as well as low gel space ratio and possible development of fine cracks are reasons of high early strength and low

later strength [3]. However, high temperature favorably affects strength gain in fly ash concrete. Several studies have reported strength increase of fly ash concrete, subjected to accelerated curing condition [4,5]. This suggests different proportion and morphology of the reaction products, from normal concrete [6].

The advantage of long-term strength prediction within a short time after mixing or placing of concrete is recognized, especially for quality control purpose. It also makes possible adjustment of mix proportions to meet the requirement if variations in material properties at site are encountered.

The acceleration of concrete strength development by high temperature curing for the purpose of later age strength prediction has been of interest since 1927 [7]. Accelerated curing test methods have been used for normal concrete in several standards since mid 1950 [8]. ASTM C684-89 specified three test methods using normal and high curing temperatures and one method with both high temperature and pressure [9]. These methods are widely used for quality control. However, as a means to predict later age strength, shortly after mixing, these methods are not reliable, even for conventional concrete [8]. This is thought to be due to the variation in strength gain and their sensitivity to environmental condition. As mentioned before, high temperature also affects property development of concrete incorporating pozzolanic material well as normal concrete. Based on earlier reported observations, extra precautions should be taken, specifically for the following three aspects: the materials, sensitivity to temperature and performances.

Currently, the use of fly ash concrete is increasing. Since slow pozzolanic reaction requires longer time for strength development, the 56 or 91 days strength is normally specified. However, these long term strength is impractical for field adjustment or for quality control purpose. The need for means to predict the potential characteristics of fly ash concrete for quality control is more essential. At present, very little information concerning this issue is available [5,10]. It is the aim of this study, therefore, to investigate the effect of high temperature curing on microstructure and strength properties of fly ash cement mortar, using fly ash from local sources. The relevant properties are compressive, tensile and flexural strength. The information will be used for further study of strength prediction, which should benefit the quality control application in fly ash concrete construction.

MATERIALS AND SPECIMEN PREPARATION

Local lignite fly ash from three different sources namely; Mae-Moh, Ratchaburi and Rayong were used in this study. The first part of the test program was conducted to investigate the effect of fly ash from different sources on compressive strength. Then, in the second part, the effect of curing conditions on strength properties on cement mortar, using fly ash from the largest source, Mae-Moh was investigated.

Properties of fly ash in this study were as follows. The specific surface varied in the range of 3200-3900 cm^2/g, mean diameter was 68-108 micron with the total amount of SiO_2, Al_2O_3 and Fe_2O of 70-85%, CaO of 4-15% and LOI between 0.4-6.9%. The detail is shown in Table A, in the appendix. Four levels of cement replacement were used.

Coarse river sand and type I Portland cement were used in this study. The cement to sand ratio was 1:3 and water to binder ratios were 0.4 and 0.5. Warm water and Boiling Methods, specified in ASTM C684-99 [9], and some modifications were applied to fly ash cement mortar as the following. Three curing temperatures; 35°C, 75°C and 95°C were applied to two sets of two inch cube specimens immediately and 24 hours after casting. The accelerated curing duration was 3 ½ hours for 75 and 95°C, and 24 hours for the temperature of 35°C. Since the accelerated cure was conducted at the very early stage in water bath, a special care was provided to prevent specimens from direct water contact. Special plastic bags and accessories were used for this purpose. The compressive strength test was conducted in half an hour after removing specimens from the water bath. The results were compared to strength of the normally cured concrete at 2, 7 and 28 days. The 2-day strength was compared to the strength of 24-hour delayed curing.

As the major source of local fly ash, the microstructure of cement paste with Mae-Moh fly ash was investigated. The SEM and XRD Analyses Techniques were conducted on cement paste samples, both with and without fly ash under normal and high temperature curing conditions. The specimens were casted in 7.5x7.5x7.5 cm. mold as of compression specimens, to reduce size effect on temperature gradient.

RESULTS AND DISCUSSIONS

Strength Properties

The effect of curing conditions in terms of delayed time, temperature, and duration, compressive strength of mortars cured at 75°C and 95°C promptly, and 24 hours after casting were studied.

From the test results, different sources of fly ash appeared to affect strength gain from high temperature curing. However, the strength ratios of accelerated strength to the normal cured, 28 day strength (f_{acc}/f_{28day}) from each source, slightly varied. The strength ratios of the studied sources were in the range of 0.25-0.65, depending on the fly ash source and temperature levels as shown in Fig.1.

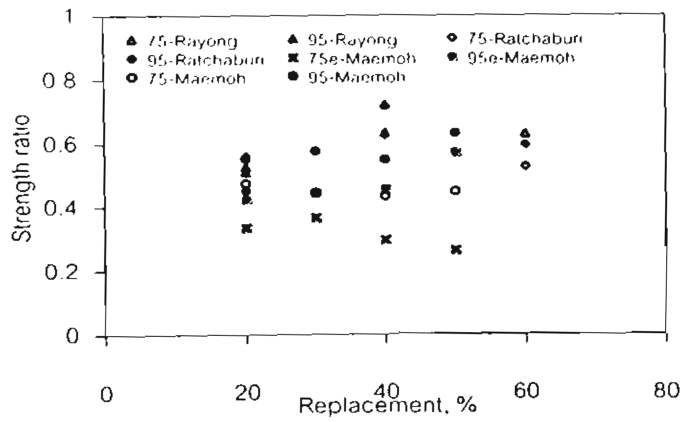


Fig.1 Effect of fly ash sources on strength ratio for W/B =0.5
Note- 75-Rayong : 75°C curing, fly ash from Rayong

The strength ratio at the replacement percentages of up to 40% appeared to be less sensitive to temperature than of those with higher replacement percentage, regardless of the fly ash sources. The water leakage which affected moisture condition of specimen during heat acceleration significantly influenced strength gain, especially for the immediate high temperature cure.

To investigate the effect of temperature and curing duration on strength properties in more details, specimens incorporating fly ash from Mae-Moh were used.

The delay in curing for 24 hours [illegible] casting before subjecting them to curing temperatures (35°C, 75 °C and 95 °C) yielded less variation in accelerated strength ratios, compared to those with no delay. The results of the promptly cured at 35°C for 24 hours also showed the same trend as shown in Fig.2. High temperature curing at either 75 or 95°C strongly affected strength development. The strengths of 95°C specimens were always significantly higher than those of 75°C, regardless of the curing method. However, the strength ratio of 75°C showed less variation.
However, considering the variation of test results and the advantage of shorter time before testing, the promptly cured procedure at 75 °C and 95°C showed potential for use in quality control work.

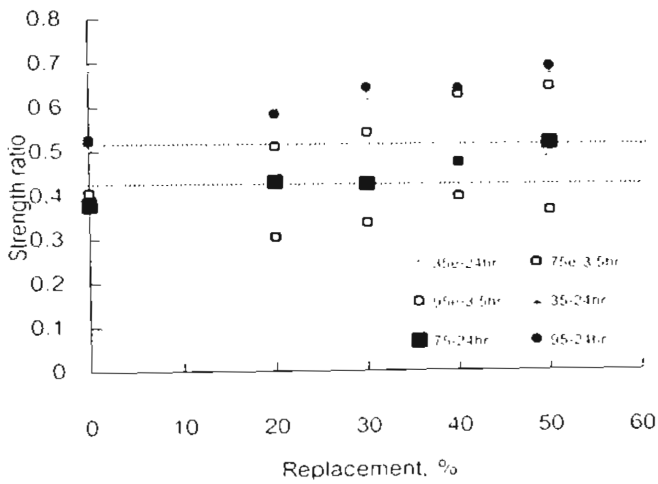


Fig.2 Effect of curing temperature and duration on strength ratio
Note: 35e-24hr = promptly cure at 35°C for 24 hr.
95-24hr = cure at 95°C for 3.5 hr after age of 24 hr.

The measurement technique of moisture loss was conducted to estimate calcium hydroxide content, using the quantitative method as suggested by Arjunan et al [11]. The test was conducted at specified temperatures (430-480°C) on paste specimens which had been cured for 3 ½ hours under 75 and 95 °C and on those normally cured for 28 day. The lower amount of calcium hydroxide in specimens from the curing temperature of 95 °C and normally cured implied increase in C-S-H, compared to those cured at 75°C (8.0% and 8.1% compared to 10.2% respectively).

Regardless of the water-binder ratio (W/B) and replacement percentage of fly ash, the relationship of compressive strength of promptly cured specimens under different accelerated curing temperature and duration and those of 28 day under normal cure condition are shown in Fig.3, as follows.

35°C for 24 hours:
$y = 0.0009x^2+0.1328x+22.467$ ....($R^2=0.984$)
75°C for 3.5 hours:
$y = 0.001x^2-0.045x+27.375$..........($R^2=0.962$)
95°C for 3.5 hours:
$y = -0.0008x^2+0.6488x+1.679$......($R^2=0.972$)

where x is the strength at 28 day under normal cure condition and y is accelerated strength under studied conditions.

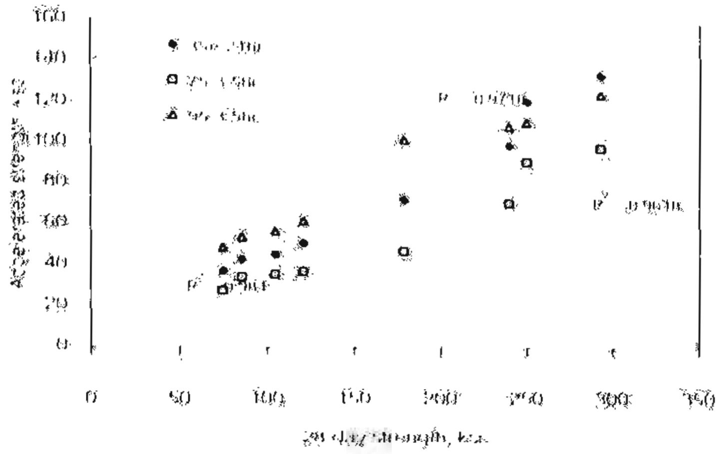


Fig.3 Relationship between accelerated strength and actual compressive strength at 28 day

Both the curing temperatures of 75°C and 95°C show less influence on tensile and flexural strength, regardless of the replacement percentage and curing duration, than on the compressive strength. The relationship of accelerated cure and those of normal cure is shown in Fig.4. For the high curing temperature of 95°C, tensile strength ratios decreased as replacement percentage increased, up to 30%. The trend is clearer for the lower curing temperature of 75 °C.

The results suggested further study could be made on the use of high temperatures, 35°C and 95 °C, promptly cured after casting for fly ash concrete

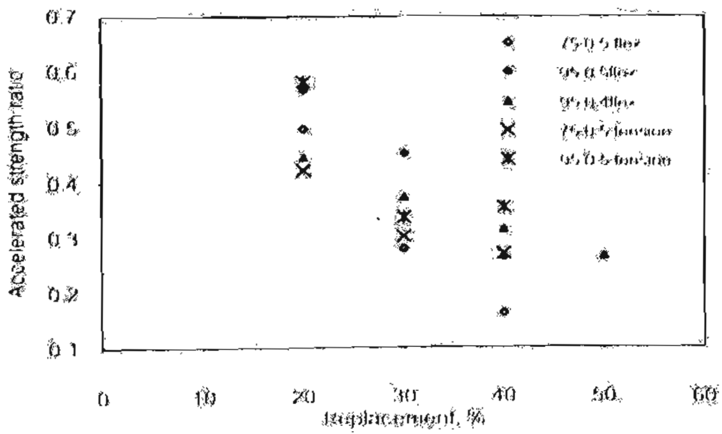
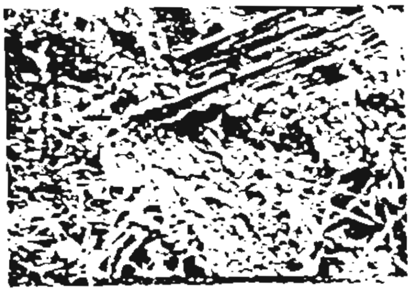


Fig.4 Relationship between accelerated strength ratio and replacement percentage for tension and flexural test.

Microstructure

Microstructure of cement paste without and with fly ash under moist cure condition, at age 7 days are shown in Figure 5. Needle-like formation of ettringite and big crystal of C-H or $Ca(OH)_2$ as well as some poor crystal of C-S-H and voids were observed in cement paste (in Fig.5a). In Fig.5b, same evidences were still observed

around smooth-surface fly ash particles. However, under high temperature 75 °C and 95 °C for 3.5 hours, cement pastes with and without fly ash appeared to develop their products significantly as shown in Fig.6 and 7. In Fig.6 a and b of neat cement paste, less needle-like formation of ettringite and agglomeration of $Ca(OH)_2$ crystal are found, as well as higher amount of voids and micro cracks, compared to of normal cure at 7days, 1 and 8 months (not shown). At 95 °C the wider micro cracks (of about 1micron) and better developed C-S-H and C-H, than of 75°C are observed. For cement- fly ash paste, Fig.7 a and b show the developed pozzolanic products on the surface of fly ash particles, the larger amount and more uniform are observed for the higher temperature, 95 °C. Some micro cracks are still observed in 3.5 hours under high temperature curing regime, compared to of 28 days under normal moist cure.

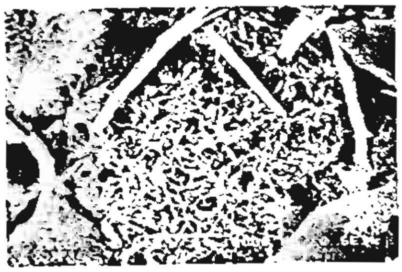


a. cement paste without flyash

b.cement paste with flyash

Fig.5 Microstructure comparison of cement paste with and without fly ash under normal moist cure at 7 day

a. 75 °C



b. 95 °C

Fig.6 Microstructure comparison of cement paste without fly ash under temperature 75 °C and 95 °C for 3.5 hours

a. 75 °C

b. 95 °C

Fig.7 Microstructure comparison of cement paste with fly ash under temperature 75 °C and 95 °C for 3.5 hours

The results of XRD analyses are shown in Figure 8, 9 and 10 for cement paste with and without flyash under normal and 75°C, 95°C curing conditions.Compared to neat

cement paste of equal age in Figure 8, peaks of C-H of fly ash-cement paste in Figure 9 were significantly lower. For high temperature curing, the comparisons in Figure 10 indicated the significant difference of C-H peaks.

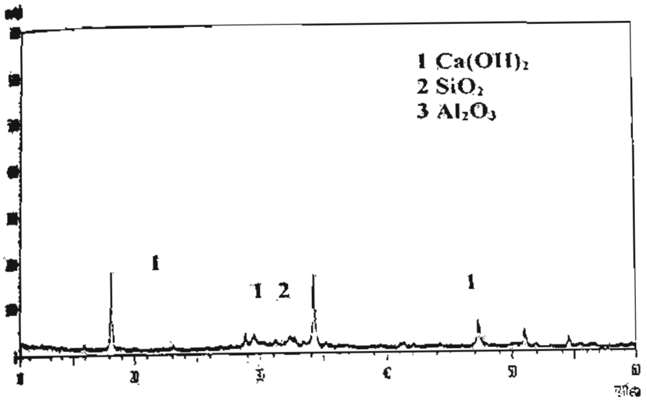


Fig. 8 XRD of neat cement paste under normal cure

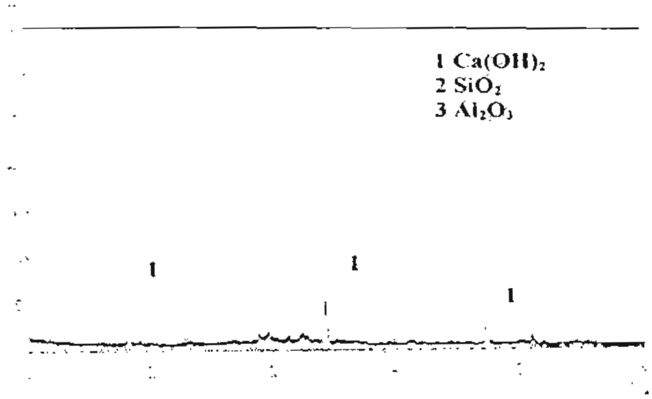


Fig. 9 XRD of fly ash cement paste under normal cure

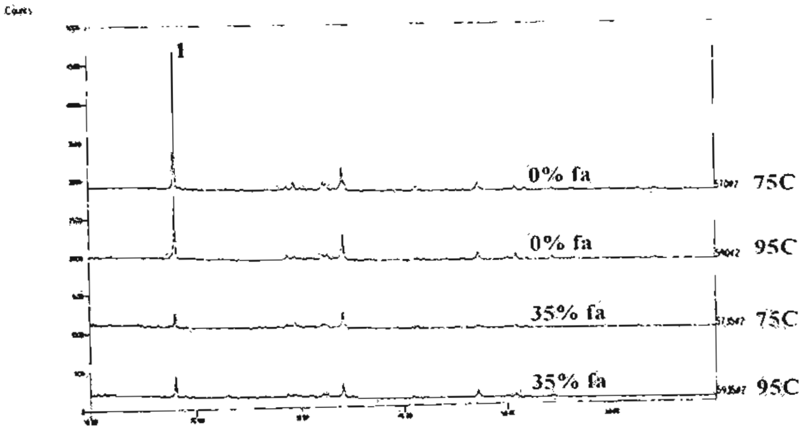


Fig. 10 XRD of cement paste with and without fly ash under high temperature cure

The peak is lower when temperature increases from 75°C to 95°C for neat cement paste. The intensity decreased from 1937 to 983 which possibly indicated the less C-H crystal formation. For fly ash neat cement paste, the much lower C-H peaks and lower intensity (357 and 445) were observed. However, the temperature effect on the detected C-H peaks is slightly less, compared to neat cement paste. From the microstructure observations, the high temperature decreased C-H but decrease the formation of hydration and pozzolanic products which lead to high strength development at the early age. The observed micro cracks at high temperature cure possibly support the evidence of less temperature influence, of 75°C and 95°C ,on tensile and flexural strength. The failure mechanism of both strength properties was different from compressive strength, which explain the increase in compressive strength but not the tensile and flexural strength.

CONCLUSION

From this study some conclusions are drawn as following:

1. Difference in sources yielded large strength difference. However, strength ratios from the various sources were close together.
2. High temperatures strongly influenced strength development of fly ash cement mortar, compared to normal mortar. The strength under 95°C was always significantly higher than the 75°C strength, regardless the curing method
3. Proposed relationship of accelerated and normal 28-day strength was in polynomial form with R^2=0.96-0.98.
4. Curing temperature of 75°C showed slightly more uniform strength and was less sensitive to replacement percentage for both compressive and tensile strength tests. Curing duration of 3.5 hours was proposed for field practice.
5. Microstructure study indicated high temperature decreased C-H and the rapid formation of hydration and pozzolanic products which lead to high strength development at the early age.

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APPENDIX

Table A Chemical and physical properties of fly ash from Mae-moh, Rayong and Ratchaburi.

Description	Mae-moh	Rayong	Ratchaburi
CaO, %	9.6	14.9	4.2
SiO_2, %	41.9	40.5	53.6
Al_2O_3, %	25.2	24.7	27.6
Fe_2O_3, %	12.8	5.4	4.4
MgO, %	2.0	1.1	1.8
SO_3, %	1.3	4.8	1.5
Na_2O, %	1.1	0.8	0.4
K_2O, %	3.1	0.9	1.4
LOI,%	0.44	6.2	6.9
MC, %	-	0.01	0.2
SpGr.	1.92	2.63	2.45
Fineness, cm^2/gm	3200	3800	3900
% retained #325	39.5	-	-

COMPARISON OF THE LATER-AGE COMPRESSIVE STRENGTH PREDICTION OF FLY ASH CONCRETE USING DIFFERENT HEAT SOURCES

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ABSTRACT

This paper reports the comparison of the later age strength prediction of fly ash concrete, using different heat sources. Fly ash concrete with target strength of 210-350 kg/cm^2 and with various percentages of cement replacement between 20-40% was investigated. The early age strength was accelerated by two different heat sources: heat source using from warm and boiling water and heat source generated by microwave energy. For warm and boiling water methods, two temperatures (75 and 95°C) were applied for 3.5 hours (1) promptly after 30-minute mixing and (2) 24 hours after mixing. Then the accelerated strength was tested 30 minutes after removing from the moulds. For microwave curing, determination of the optimal curing process was first carried out. The parameters affecting the process included the level of microwave power, the penetration resistance level, and the rest time. Then the process was applied to all mixes to obtain the accelerated strength. For both methods of heating, correlation between early and later age strength could be established. The later age strength was tested on normally-cured specimens at 28, 56 and 91 days. The established equation for later-age strength prediction for both methods yielded the error within ±11%.
KEYWORDS: accelerated curing, boiling, microwave, fly ash concrete

INTRODUCTION

The use of local fly ash in concrete industry is significantly increasing. Besides the economic aspect, the use of this pozzolanic material as a partial cement replacement results in some improvement of concrete properties including increasing workability, reducing heat of hydration, reducing permeability and increasing durability. The pozzolanic reaction occurs much slower than cement hydration reaction; therefore, microstructure and strength development of fly ash concrete requires longer time than those of Portland cement concrete. The strength test at 56 or 91 days which is normally specified for fly ash concrete becomes impractical, especially for construction quality control purpose. The need to know potential characteristics of concrete within a short time after mixing or being placed in the structure is essential for possible mix proportion adjustment to meet the requirement if variations in material properties at site are encountered.

Accelerated strength test to obtain advanced evaluation of strength variation has long been recognized. Many research works have been widely carried out and many published articles are available. Kasai (1990) collected and described the accelerated strength methods used in Japan. Those methods aim to predict the later age strength at 28 days by accelerating early age strength using different means. Heat acceleration from hot water was the mostly used method. Some reported methods provided the content evaluation of cement, water and water/cement ratio. Leung and Pheeraphan (1997) proposed the use of microwave energy to accelerate early strength of concrete. The method provides high early age strength with less long-term strength drop. Pheeraphan et. al. (2002) reported the method to predict later-age strength of normal concrete, using the accelerated strength of the same concrete cured with microwave energy, is possible within only 3.5 and 5.5 hours for rapid hardening and ordinary Portland cement, respectively. For each cement type, the prediction using a formula derived from the relationship between the accelerated early-age strength and the later-age strength of normal-cured concrete yields within about ±15 percentage of error.

This paper reports the comparison of later-age strength prediction of fly ash concrete using two different heat sources to accelerate the early strength. The heat sources included heat source using from warm and boiling water according to or slightly modified from ASTM C684, and heat source generated by microwave energy originally developed by Pheeraphan et. al. (2002). The objective of this study was to estimate the long-term compressive strength at 28, 56 and 91 days of fly ash concrete. The information from this study was expected to benefit the quality control of fly ash concrete construction.

EXPERIMENTAL PROGRAM

Material

Local fly ash from Maemoh, Lampang province, was used in this study. The chemical compositions and some physical properties were investigated and the results are shown in Table 1. Portland cement type I, which was used throughout this study, was partially replaced by fly ash at 0, 20, 30 and 40% by weight. The mix proportions, designed according to the ACI method with controlled slump of 8-10 cm., are shown in Table 2. The maximum size of aggregate was 9.5 mm. No chemical admixture was added to the mix in this study.

Table 1 Chemical composition and some physical properties of fly ash

Chemical Composition	%by weight
SiO_2	46.57
Al_2O_3	24.14
Fe_2O_3	8.97
CaO	10.39
MgO	2.76
Na_2O	1.72
K_2O	2.81
SO_3	1.61
Loss on Ignition	0.50
Specific Gravity	2.00
Blaine Fineness (cm^2/g)	2430

Table 2 Mix proportions of fly ash concrete

Mix #	water/ binder	% Fly Ash replacement by weight	Water Kg/m^3	Cement Kg/m^3	Fly Ash Kg/m^3	Lime-Stone Kg/m^3	Sand Kg/m^3
1	0.4	0	228	570	0	698	793
2		20	228	456	114	698	739
3		30	228	399	171	698	711
4		40	228	342	228	698	684
5	0.5	0	228	456	0	698	888
6		20	228	365	91	698	844
7		30	228	319	137	698	823
8		40	228	274	182	698	801
9	0.6	0	228	380	0	698	951
10		20	228	304	76	698	915
11		30	228	266	114	698	897
12		40	228	228	152	698	878

Equipment

The 0.85x1.25x0.85 m curing tank with the capability to control temperature in the range of 25-110 °C was used in this study.

The commercial microwave (0.375x0.251x0.392 m.) with maximum output power of 900 watts (IEC-705 standard) was used.

Specimen preparation and curing process

In each mix, 32 cylindrical specimens, 3 inch in diameter 6 inch in height were cast and separated in to three groups. The first group was moist cured for 24 hours and water cured after demolding until the tested age at 28, 56 and 91 days. Four specimens were tested at each age.

The second group was divided into two sub groups. The first sub group was sealed in the special case and promptly water cured in controlled temperature tank of 75 and 95°C for 3.5 hours before demolding and tested within 30 minutes. Four specimens were tested for each temperature. The second sub group, 8 specimens, were moist cured for 24 hours before demolding and put in special cases, water cured under controlled temperature of 75 and 95°C for 3.5 hours and tested within 30 minutes, similar to the first sub group. Four specimens were tested for each temperature.

The third group was conducted under microwave-cured condition. The fresh concrete was sieved through sieve no.4 to test the penetration resistance according to ASTM C403. After reaching the specific levels of penetration resistance, four specimens were cured with microwave energy for 45 minutes. After microwave curing, using a thermocouple to check the temperature drop in the middle of one specimen used as a reference. The rest of the specimens were covered with plastic sheet until the temperature reach 40°C to test for compressive strength.

The optimal process for microwave curing

The lowest microwave energy to obtain the high early age strength and low strength loss at the later age was the criteria used in this study. Several considered factors which affected the optimal process for microwave curing were power level, delay time which was the total time between the cement contacted water and the time before application of microwave energy, total heating time, and rest time which was the total time between the time after removed specimens from microwave oven and the time before testing. Delay time depending on that the sieved mortar needed to reach the specified penetration resistance. Curing duration in this study was 45 minutes, according to the previous study of Leung and Pheeraphan (1997). Rest time was determined by measuring the temperature inside the history after removing the specimen from microwave oven and measured temperature of specimen was dropped to below 40 °C.

RESULTS AND DISCUSSION

Results of microwave power output

The results of microwave power verification which was tested according to IEC-705 Method from Voss and Greenwood-Madsen (1987) is shown in Fig. 1. Linear regression was applied to find the correlation between the measured power output and level of power used.

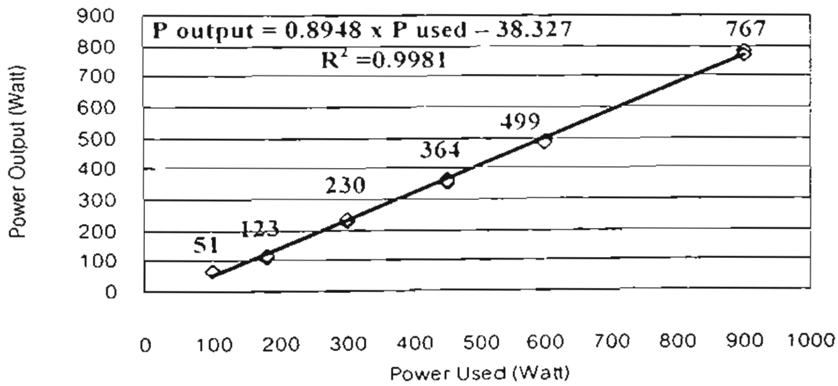


Fig. 1 Microwave Power Output Calibration

Results of optimal process for microwave curing

To determine the optimal microwave power, the test was conducted on mix #7. The delay time before microwave curing was set to be 30 minutes according to the previous results from Pheeraphan et. al. (2002). For each power level, specimens were put through accelerated curing for 45 minutes and then placed at room temperature until test. Compressive strength tested was conducted when the measured temperature of these specimens reached 40°C, which generally required about 3.5 hours. The relationship of elapsed time and temperature drop for each power level is shown in Fig. 2. The accelerated strength was compared with the compressive strength at 14 days of microwave cured specimens (MCC) and of normal cured specimens (NCC), as shown in Fig. 3. The results showed that the optimal power was at 364 watts for 15 minutes and 230 watts for 30 minutes, termed as 364/15+230/30, since the early strength of MCC was high while the later strength of MCC was comparable to that of NCC.

To determine the delay time, mix #7 was used. Here, the penetration resistance in the range of 0-1000 psi was used to determine the proper delay time. After the specimen reached the specified penetration resistance, the determined optimal power was applied to the specimen and tested at 14 days to compare with the strength of specimen under standard condition at the same age. The test results of 14-day strength

or each penetration resistance was shown in Fig. 4. The strength difference of the two ases from each delay time was quite small, in the range of 0-10%. The longer resting ime, longer than 3.75 hr of which the penetration resistance ranged between 400-1000 si, the difference was close to 1%. The maximum compressive strength was obtained rom zero penetration resistance condition. Therefore, the delay time of 30 minutes, rom mixing, which was the condition of specified zero penetration resistance was used hroughout this study.

To determine the rest time, mix #4, 9 and 12 were used while the delay time was ept at 30 minutes before accelerating the specimens with optimal power for 45 minutes. After removing the specimens from microwave curing, measure the temperature in the niddle of the specimen. The result in Fig. 5 showed that it took about 3 hours for emperature to reach 40°C. To obtain better accuracy in strength measurement, the esting time was therefore selected to be at 3.5 hours. It is important to note that the rocess for demoulding and capping specimens required about 30 minutes after 3.5 rest ime. Therefore, the total rest time at 4 hours was used to establish the correlation etween the accelerated strength and later-age strength.

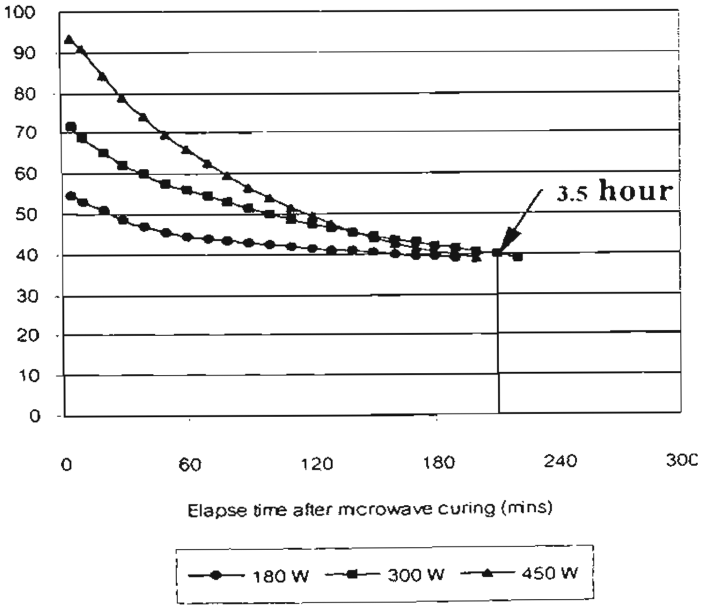


Fig. 2 Temperature history for determination of rest time

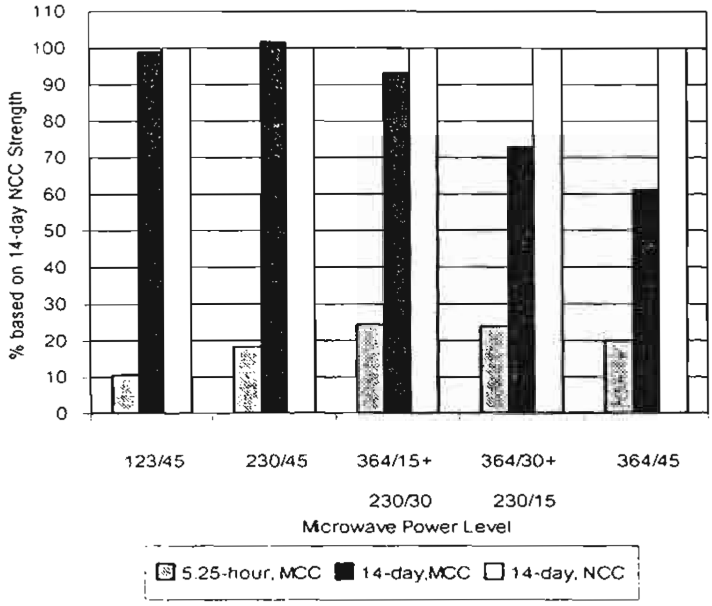
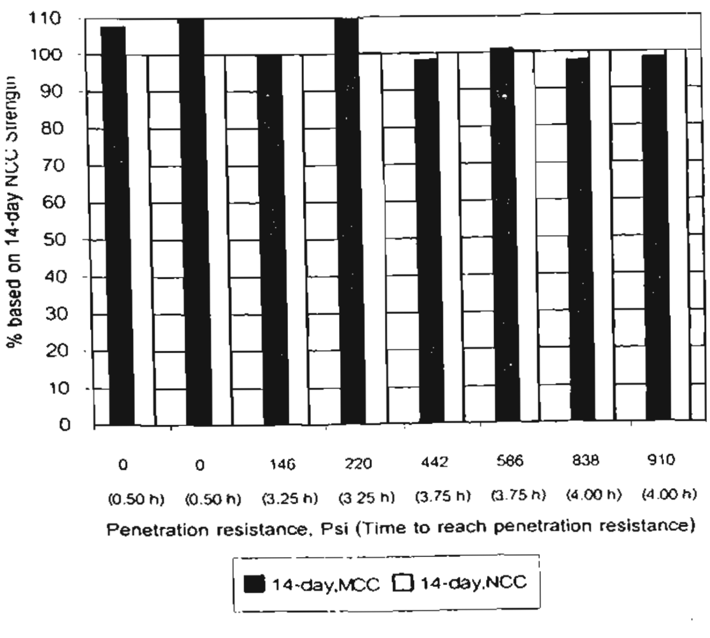
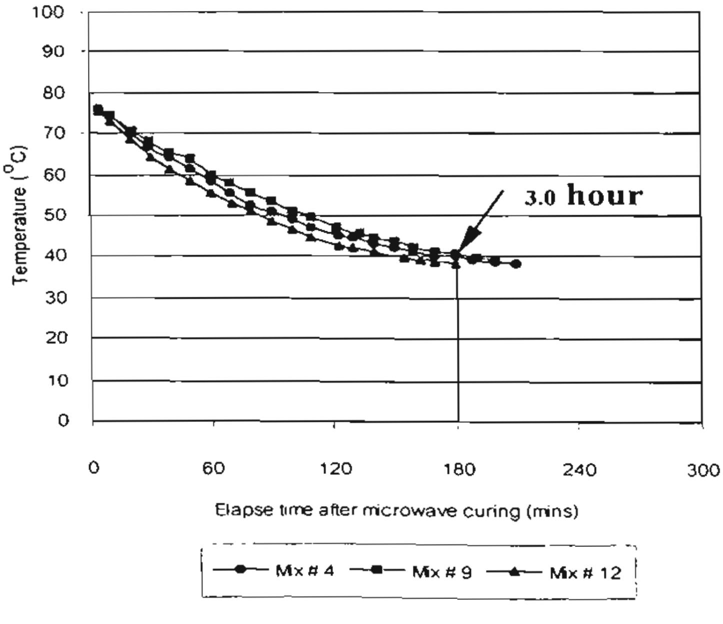


Fig. 3 Effect of microwave power application on compressive strength of concrete





To conclude, the optimal microwave curing process could be described that the specimens under the optimal condition were mixed for 30 minutes before heating with an optimal power at 364 watts for 15 minutes and 230 watts for 30 minutes, then the specimens were moistly cured for 3.5 hours before removing and testing for 30 minutes.

Correlation of accelerated strength and later-age strength

The obtained compressive strength from each accelerated curing condition under the predetermined process and chosen conditions are shown in Table 3. The relationship between the accelerated compressive strength and later age strength of normal moist curing were plotted in Fig. 6a-e. The established relationship was in the exponential form as shown in equation (1)

$$S_l = K_1 S_e^{K_2} \tag{1}$$

Where S_l = compressive strength of normal condition at 28, 56 and 91 days
S_e = early age compressive strength of accelerated curing condition
K_1, K_2 = constants as shown in Table 4

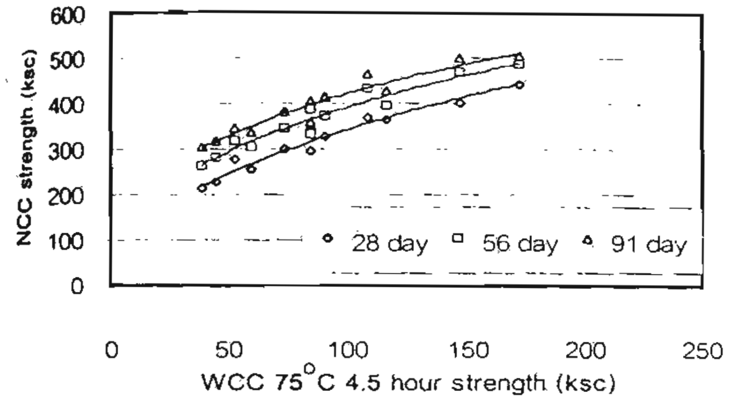
Table 3 Test results of compressive strength by accelerated and normal curing

Mix #	w/b	% by weight	Compressive Strength (ksc) at age							
			WCC 75°C		BCC 95°C		MCC	NCC		
			4.5 h	28 h	4.5 h	28 h	5.25 h	28 d	56 d	91 d
1	0.4	0	172.13	218.05	117.78	239.83	141.33	442.14	487.15	503.84
2		20	147.31	200.50	156.58	218.50	114.65	399.86	467.52	493.30
3		30	108.75	160.32	124.64	181.75	91.61	370.33	430.96	461.98
4		40	84.91	148.46	112.51	176.94	70.25	339.47	386.82	404.95
5	0.5	0	116.78	167.31	117.19	183.84	92.84	363.65	395.41	428.03
6		20	90.56	139.87	99.76	155.80	69.33	325.45	371.01	414.30
7		30	73.38	117.39	86.55	136.18	52.17	300.33	347.58	381.36
8		40	53.02	92.68	68.89	117.77	43.58	276.52	316.60	345.91
9	0.6	0	85.00	131.54	90.83	138.88	61.41	295.64	331.07	357.98
10		20	59.92	91.31	69.47	104.72	44.31	254.22	302.99	338.58
11		30	44.36	79.75	59.65	92.74	27.33	225.99	280.16	318.55
12		40	39.17	71.53	56.82	88.31	20.70	212.08	264.41	304.44

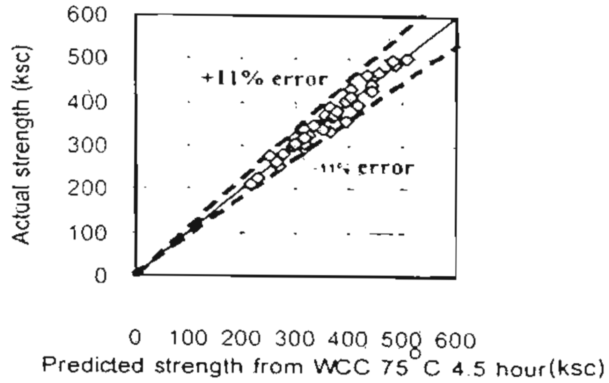
Note: WCC = warm water cured concrete BCC = boiling water cured concrete
MCC = microwave cured concrete NCC = normal cured concrete

Table 4 Parameters K in equation (1) with different age

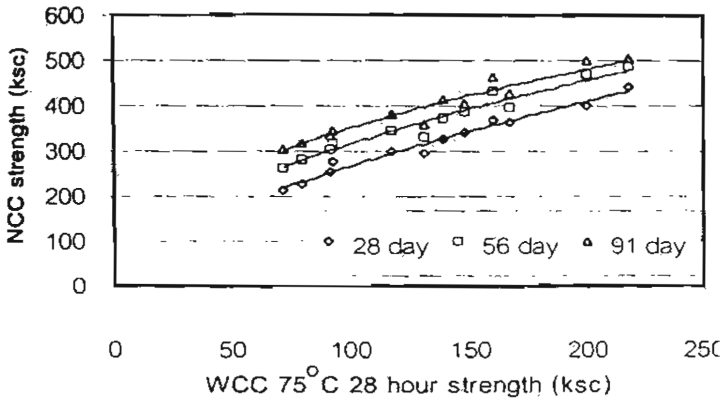
Method	Parameters K at age					
	28 days		56 days		91 days	
	K_1	K_2	K_1	K_2	K_1	K_2
WCC 75°C - 4.5 hour	37.844	0.478	58.774	0.4112	82.606	0.3535
WCC 75°C - 28 hour	15.593	0.6168	27.499	0.53	43.482	0.4534
BCC 95°C - 4.5 hour	19.775	0.6035	32.614	0.5259	50.256	0.4501
BCC 95°C - 28 hour	10.192	0.6854	18.965	0.902	31.904	0.5032



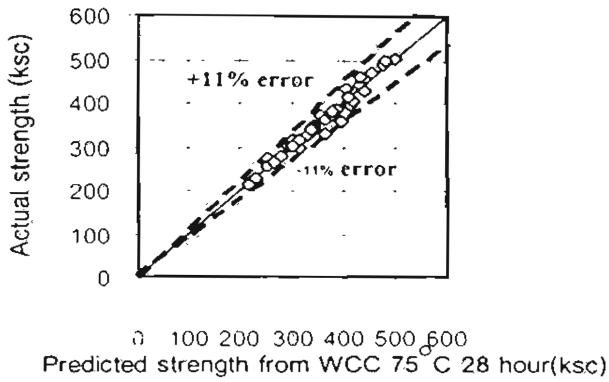
6 (a)



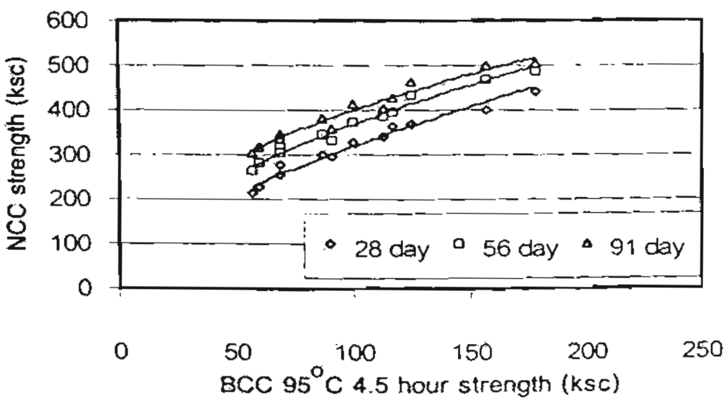
7 (a)



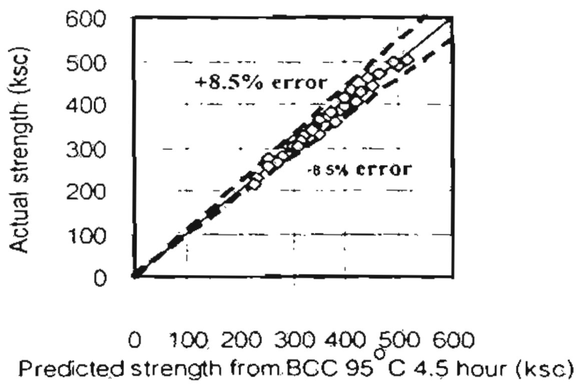
6 (b)



7 (b)



6 (c)



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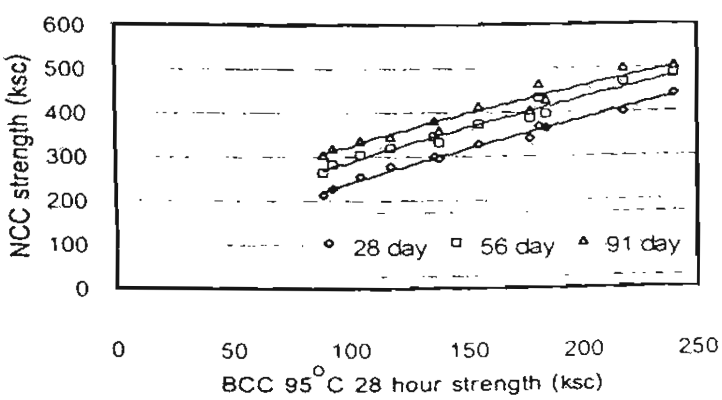

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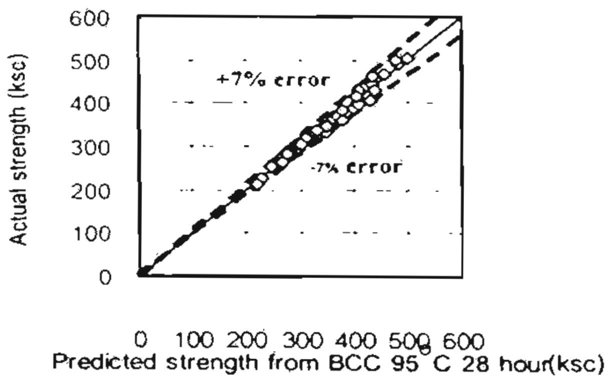
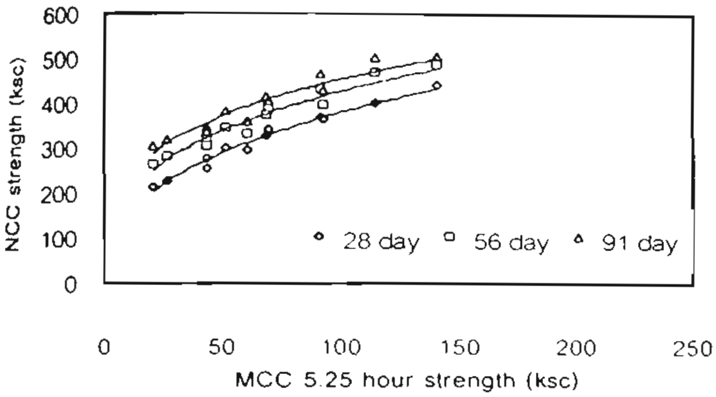
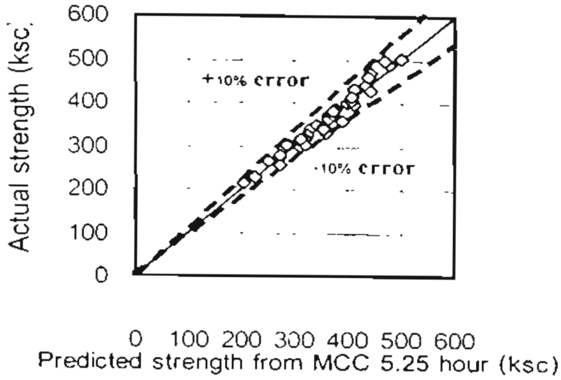




6 (e)

Fig. 6 Compressive strength of early accelerated curing by (a) WCC 75°C-4.5 hours (b) WCC 75°C-28 hours (c) BCC 95°C-4.5 hours (d) BCC 95°C-28 hours and (e) MCC-5.25 hours versus later-age normal curing



7 (e)

Fig. 7 Comparison of actual and predicted concrete strength calculated from accelerated curing methods (a) WCC 75°C-4.5 hours (b) WCC 75°C-28 hours (c) BCC 95°C-4.5 hours (d) BCC 95°C-28 hours and (e) MCC-5.25 hours

Equation (1) could then be used to predict the compressive strength of normally cured concrete with and without fly ash as cement replacement in the range of 20-40% once the accelerated strength and the percent replacement of fly ash are provided. It was found that the percentages of error were ±11, ±11, ±8.5, ±7 and ±10% for 75 °C, 95°C promptly curing, 75°C, 95 °C after 24 hours, and microwave curing, respectively. Fig. 7a-d showed the actual and predicted compressive strength.

It is important to note that the boiling curing method and microwave curing method could be used to predict the later-age strength as early as 4.5 and 5.25 hours after mixing, respectively.

CONCLUSION

From this study it was found that the accelerated curing could be satisfactorily applied to fly ash concrete. Heat sources generated by commercial microwave oven can be used, under optimal process, to obtain results within acceptable limit of percentage of error of ±10% in only 5.25 hours after mixing. Heat source using from warm and boiling water can also be directly applied, with the acceptable limit of percentage of error of ±7-11%, depending on curing conditions, within as early as 4.5 hours.

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หน้าสรุปโครงการ

การใช้การเร่งกำลังด้วยความร้อนในการทำนายกำลังและคุณสมบัติด้านความทนทานของคอนกรีตผสมเถ้าลอย

ในปัจจุบันแนวโน้มของการใช้คอนกรีตผสมเถ้าลอยในงานก่อสร้างภายในประเทศมีสูงขึ้นมาก เนื่องจากคุณสมบัติของเถ้าลอยที่ผลิตได้ในประเทศมีคุณภาพดีขึ้น และมีรายงานการศึกษาถึงศักยภาพของการนำมาใช้ในงานก่อสร้างสูง นอกจากนั้นการนำมาใช้งานคอนกรีตในแง่ของการแทนที่ซีเมนต์ในปริมาณมากยังส่งผลดีในเชิงของการลดปัญหาสิ่งแวดล้อมและการจัดการอีกด้วย แต่คุณสมบัติที่สม่ำเสมอจากแหล่งต่างๆ ในประเทศ หรือแม้แต่แหล่งเดียวกันยังเป็นประเด็นสำคัญสำหรับคุณภาพของคอนกรีต

ดังนั้นวิธีการที่ใช้ในการตรวจสอบและควบคุมคุณภาพของคอนกรีตผสมเถ้าลอยจึงเป็นเรื่องสำคัญและจำเป็นในขั้นการปฏิบัติงาน คอนกรีตผสมเถ้าลอยมีพฤติกรรมการพัฒนาโครงสร้างภายในต่างไปจากคอนกรีตธรรมดาซึ่งจะเป็นผลสืบเนื่องไปถึงคุณสมบัติต่างๆของผลิตภัณฑ์คอนกรีต ปฏิกิริยาPozzolanicซึ่งเป็นปฏิกิริยาในขั้นที่ 2 เกิดขึ้นช้ากว่าปฏิกิริยา hydration ตามปกติของซีเมนต์ทำให้ต้องพิจารณาคุณสมบัติต่างๆที่อายุนานกว่าคอนกรีตปกติ โดยทั่วไปนิยมทำการทดสอบคุณสมบัติต่างๆของคอนกรีตผสมเถ้าลอยที่อายุ 56 หรือ 91 วัน ซึ่งจัดว่านานมากสำหรับกระบวนการควบคุมคุณภาพ วิธีการทดสอบที่ใช้เวลาสั้นๆ จะเป็นประโยชน์ต่อการควบคุมคุณภาพและความสม่ำเสมอของวัสดุซึ่งจะช่วยให้สามารถปรับเปลี่ยนวัสดุ ส่วนผสมและวิธีการทำงานให้เหมาะสมซึ่งจะช่วยให้สามารถพัฒนาคุณภาพคอนกรีตให้เป็นไปตามความต้องการได้ทันเวลาและเหมาะสมในแง่เศรษฐศาสตร์ ประเทศไทยยังมิได้มีแนวทางปฏิบัติสำหรับการทดสอบเพื่อการควบคุมคุณภาพโดยตรง ดังนั้นงานวิจัยเกี่ยวกับการเร่งกำลังคอนกรีตผสมเถ้าลอยด้วยความร้อนจะเป็นงานที่รองรับการใช้คอนกรีตดังกล่าวในอุตสาหกรรมก่อสร้าง

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลกระทบของความร้อนจากการบ่มต่อคุณสมบัติและพฤติกรรมต่างๆของมอร์ตาร์และคอนกรีตผสมเถ้าลอยในด้านการพัฒนากำลัง รวมถึงคุณสมบัติด้าน ความคงทนบางประการ และเปรียบเทียบการพัฒนาโครงสร้างภายในของคอนกรีตผสมเถ้าลอยที่บ่มด้วยมาตรฐานและวิธีเร่งกำลังด้วยความร้อนหลายระดับที่อายุต่างๆเพื่อเป็นแนวทางพิจารณาหาวิธีการทดสอบการเร่งกำลังที่เหมาะสมของคอนกรีตผสมเถ้าลอยเพื่อใช้เป็นวิธีตรวจสอบและควบคุมคุณภาพในระยะเวลาสั้นสำหรับก่อสร้าง

การศึกษาวิจัยนี้แบ่งเป็น 2 ขั้นตอน ขั้นตอนแรก เป็นการศึกษาจากชิ้นตัวอย่างมอร์ตาร์ โดยรวมถึงการศึกษาผลกระทบของอุณหภูมิต่อมอร์ตาร์ผสมเถ้าลอยที่มาจากต่างแหล่ง ขั้นตอนที่สองเป็นการศึกษาชิ้นตัวอย่างคอนกรีต โดยมีวิธีการวิจัยดังนี้ ในขั้นแรก ทำการหล่อชิ้นตัวอย่างรูปลูก

บาศก์ขนาด 5 ซม. สำหรับมอร์ตาร์ควบคุมและมอร์ตาร์ที่ผสมเถ้าลอย และแบ่งชิ้นตัวอย่างเป็น 3 ชุด ชุดแรกบ่มชื้นปกติ ชุดที่ 2 บ่มด้วยวิธีเร่งกำลังด้วยความร้อนทันทีในถังบ่มที่ควบคุมอุณหภูมิ 35 °C สำหรับวิธี Warm water, 75° °C สำหรับวิธี Modified Method และ 95 °C สำหรับวิธีการต้ม โดยใช้เวลา 24, 3 ½ และ 3 ½ ชม. ตามลำดับ และทดสอบภายใน 1/2 ชม. ชุดที่ 3 นำมาบ่มด้วยวิธีเร่งกำลังด้วยความร้อนเมื่อมีอายุครบ 24 ชม.ในถังบ่มที่ควบคุมอุณหภูมิ เช่นเดียวกับตัวอย่างชุดที่ 2 โดยใช้เวลา 24,3 ½และ 3 ½ชม. ตามลำดับ ก่อนจะทดสอบภายใน ½ ชม.ใช้วิธีทางสถิติหาความผันแปร และความสัมพันธ์ระหว่างกำลังจากการบ่มด้วยวิธีต่างๆ เปรียบเทียบกับกำลังระยะยาว เพื่อเลือกวิธีและช่วงเวลาที่เหมาะสมเพื่อศึกษาในขั้นต่อไป

ในขั้นที่สองหล่อชิ้นตัวอย่างรูปลูกบาศก์ ขนาด 7.5 ซม. จากส่วนผสมคอนกรีตควบคุมและคอนกรีตผสมเถ้าลอย โดยทำการหล่อตัวอย่างรูปทรงกระบอกมาตรฐาน 15x30 ซม. จากส่วนผสมเดียวกันเพื่อทดสอบเปรียบเทียบ ทำการเตรียมตัวอย่างและทดสอบเช่นเดียวกับตัวอย่างมอร์ตาร์ นอกจากนั้นยังทดสอบตัวอย่างรับแรงดัดและแรงดึงด้วยรวมถึงศึกษาการพัฒนาโครงสร้างภายในด้วยวิธี scanning electron microscope(SEM) และX-Ray Diffraction (XRD) โดยตัดชิ้นตัวอย่างซีเมนต์เพสต์ทั้งที่ผสมและไม่ผสมเถ้าลอย ที่บ่มเร่งกำลังและที่ใช้วิธีบ่มปกติศึกษาเปรียบเทียบกัน

ในด้านความคงทน ศึกษาความต้านทานการแทรกซึมของคลอไรด์โดยใช้ตัวอย่างที่ได้รับการบ่มด้วยวิธีต่างๆและชิ้นตัวอย่างที่บ่มด้วยวิธีมาตรฐาน ทดสอบด้วยวิธีRapid Chloride Permeability เพื่อหาความสัมพันธ์ที่อาจมี นอกจากนั้นศึกษาความต้านทานการขยายตัวจากซัลเฟต โดยแช่ตัวอย่างที่ได้รับการบ่มด้วยวิธีต่างๆและบ่มด้วยวิธีมาตรฐานในสารละลายซัลเฟตโดยวัดการเปลี่ยนแปลงความยาวเป็นระยะ

ผลการศึกษาพบว่าเถ้าลอยจากต่างแหล่งซึ่งมาจากวัตถุดิบและกระบวนการผลิตต่างกัน มีองค์ประกอบทางเคมีและคุณสมบัติทางกายภาพค่อนข้างแตกต่างกัน และแหล่งของเถ้าลอยมีผลกระทบต่อการพัฒนากำลังอัดแต่ไม่มีผลกระทบชัดเจนเมื่อพิจารณาในเชิงอัตราส่วนของกำลังจากวิธีบ่มเร่งต่อกำลังจากวิธีบ่มปกติที่อายุ28วัน การบ่มอุณหภูมิสูงมีผลต่อการพัฒนากำลังทั้งแรงอัด แรงดัดและ แรงดึงในระยะต้น โดยเฉพาะแรงอัด มีความผันแปรอยู่ในช่วงร้อยละ 10 กำลังอัดของมอร์ตาร์ที่บ่ม 95° °C มีค่าสูงกว่าการบ่มที่75° °C การบ่มโดยใช้อุณหภูมิ ต่ำ เป็นเวลา 24 ชม. ให้ผลไม่แตกต่างจากการบ่มอุณหภูมิห้องมากนักที่อายุเดียวกัน ความสัมพันธ์ระหว่างค่าอัตราส่วนกำลังจากการบ่มเร่งต่อกำลังจากการบ่มปกติที่อายุ 28 วัน อยู่ในช่วง 0.2 – 0.60 ขึ้นอยู่กับสัดส่วนเถ้าลอยและระดับอุณหภูมิ และการยืดระยะเวลาการบ่มเร่ง มีผลต่อการลดความผันแปรของค่าอัตราส่วนกำลัง ค่ากำลังอัดจากการบ่มเร่งมีความสัมพันธ์กับกำลังอัดจากการบ่มปกติค่อนข้างชัดเจน ทั้งอัตราส่วนกำลังดัดและกำลังดึงมีค่าลดลงตามปริมาณการแทนที่ที่เพิ่มขึ้น

จากการศึกษาคอนกรีตพบว่า การบ่มด้วยอุณหภูมิสูง 3.5 ชม.มีผลต่อทั้งคอนกรีตควบคุมและคอนกรีตผสมเถ้าลอยทุกระดับการแทนที่ สำหรับคอนกรีตปกติ ค่าเฉลี่ยกำลังอัดจากการบ่ม

เร่งกำลังอุณหภูมิสูงในแต่ละกรณีมีค่าแตกต่างกันอย่างมีนัยสำคัญทางสถิติแต่ค่าเฉลี่ยของการบ่มเร่งหลังจากยืดเวลา 24 ชั่วโมงไม่มีแนวโน้มชัดเจน และความสัมพันธ์ของค่ากำลังอัดของคอนกรีตควบคุมจากการบ่มเร่งหลังยืดเวลาไปแล้ว 24 ชั่วโมงกับกำลังอัดระยะยาว 28 และ 56วันมีความผันแปรน้อยกว่ากรณีการบ่มเร่งทันที

การบ่มอุณหภูมิสูงมีผลต่อการพัฒนากำลังสำหรับคอนกรีตผสมเถ้าลอยมาก และทั้งปริมาณการแทนที่และระดับอุณหภูมิที่ใช้บ่มมีผลต่อการเร่งกำลัง และการทำนายกำลังอัดระยะยาว ค่ากำลังอัดจากการบ่มเร่งมีความสัมพันธ์กับระดับอุณหภูมิ W/B และปริมาณการแทนที่ในลักษณะเชิงเส้น แต่ผลกระทบจากและความแตกต่างจากผลกระทบระดับอุณหภูมิต่อค่าอัตราส่วนกำลังมีน้อยกว่าเมื่อเทียบกับกรณีของกำลังอัด

ผลกระทบจากอุณหภูมิต่อความต้านทานการขยายตัวจากเกลือซัลเฟตของคอนกรีตผสมเถ้าลอยมีพฤติกรรมค่อนข้างแตกต่างจากคอนกรีตปกติ แต่ข้อมูลการแช่ระยะสั้นมีความผันแปรมากไม่อาจสรุปได้ชัดเจน คอนกรีตควบคุมและคอนกรีตผสมเถ้าลอยทุกระดับการแทนที่ ที่บ่มด้วยอุณหภูมิสูง 3.5 ชม.มีค่าความต้านทานการซึมได้ของคลอไรด์ต่ำ จนไม่อาจวัดได้ แต่ผลกระทบจากอุณหภูมิสูงยังคงมีผลต่อความต้านทานการซึมได้แม้เมื่อบ่มต่อที่อุณหภูมิปกติ ทั้งในคอนกรีตปกติและคอนกรีตผสมเถ้าลอย อุณหภูมิสูงมีผลต่อการพัฒนาโครงสร้างภายในอย่างชัดเจนและมี อิทธิพลต่อการเกิดปฏิกริยา pozzolanic ในระดับที่แตกต่างกัน

เมื่อพิจารณาถึงผลกระทบของอุณหภูมิสูงจากทุกสภาวะการบ่มต่อการพัฒนากำลัง ทั้งกำลังอัด กำลังดัด และกำลังดึงและความเหมาะสมหรือความสะดวกในการใช้งาน อาจสรุปได้การบ่มด้วยอุณหภูมิสูง 3.5 ชม.ทันทีมีความเหมาะสมในการประยุกต์ใช้เป็นวิธีตรวจสอบและควบคุมคุณภาพในระยะเวลาสั้นๆ ทั้งอุณหภูมิ75°C และ 95°C ให้ความสัมพันธ์กับ กำลังอัดระยะยาวที่มีความน่าเชื่อถือได้ทางสถิติ

Executive Summary

Heat accelerated test to predict strength and durability properties of fly ash concrete

The reported high pozzolanic reactivity and the favorable physical characteristics of the local fly ash, coupled with economic, management and environmental factors, help accelerate fly ash utilization in concrete industry to unprecedented degree, with still ever increasing trend. However, the uniformity of fly ash both from different sources and from the same sources but different production time is still questionable for quality of final concrete. Therefore, the means for quality control during construction become necessary.

The large amount of replaced fly ash significantly affects microstructure development of concrete and its properties as well as performances. The delayed pozzolanic reaction, which is normally slower than cement hydration reaction, required longer period for property's development than normal concrete. The common strength at 56 or 91 days is impractical for field adjusting or for quality control purpose. Therefore, the means to predict the potential characteristics at the early age is essential for quality control and corrective measure for fly ash concrete. This will help check material uniformity, adjusting material, proportion and operation to meet the requirement in time and economically, Presently in Thailand, little information concerning this issue is available and there is no specific guideline for quality control of fly ash concrete available. The information from this study is expected to provide the basis for an adaptive approach for concrete industry, using high temperature to estimate strength of fly ash concrete for quality control purpose.

This report aimed to investigate the effect of high curing temperature on strength development and the resistance to sulfate attack, and chloride penetration. It also attempted to follow the temperature effect on the development of the microstructure and compare to that of the standard curing condition, to aid finding accelerated early strength method for quality control of fly ash concrete.

The first part of this study investigated the effect of different fly ash source as well as the effect of high curing temperature and duration on fly ash cement mortar while the second part involved the effect on concrete and microstructure, with the following parameters. Five cement replacement percentages, namely 0, 20,30,40 and 50; 3 levels of water/binder ratios, viz, 0.40, 0.50 and 0.60; and three curing conditions, namely standard and high temperature curing promptly and after 24 hours of casting for 3 ½ hours. The test was conducted within ½ hour after specimen removal from curing condition. Statistical analysis was used as a tool to compare and investigate the relationship from the study. Flexural and tensile test were also conducted, in addition to chloride permeability test and sulfate resistance test, combined with microstructure study using SEM and XRD to investigate the performance related properties development.

The results indicated favorable outcome of accelerated curing from the inclusion of fly ash in concrete. Different sources of fly ash which yielded different chemical composition and physical properties appeared to affect individual strength gain, but not the ratios of accelerated strength to strength at 28 days. High curing temperatures strongly influence strength development of fly ash cement mortar, including compressive, tensile and flexural strength. The ratios of accelerated compressive strength to strength at 28 days varied within 10 percent range. The strength of both mortar and concrete under 95°C curing is always significantly higher than of 75°C curing, regardless to the used condition. The strength ratios of fly ash mortar were found to be in the range of 0.20-0.60, depending on percent replacement, and temperature level. Delayed curing condition clearly reduced the variation of strength ratio. The clear relationship between accelerated compressive strength and normal cure compressive strength was found. The strength ratio of compressive, flexural and tensile strength decreased as the percent replacement increased.

The results from the second part revealed the strong effect of prompt curing under both high temperature levels, 75°C and 95°C on strength development of concrete both with and without fly ash. For normal concrete, the difference in means of compressive strength from both temperature in each condition was statistically significant. However, the difference in means of the delayed accelerated cure compressive strength under 75°C and 95°C was not clear. The variation of the relationship between accelerated and normal compressive strength was less in this case than that of the prompt curing. High temperature curing strongly affected strength development of fly ash concrete. Both replacement percentage and temperature level affect strength development and later age strength prediction. The relationship of accelerated and temperature, w/b and percentage replacement was found to be linear. However, the effect from temperature level on flexural strength ratio was less than that of compressive strength.

The effect of temperature on resistance to sulfate expansion was not clear. The only conclusion that could be drawn from the wide variation of the limited data was the behavior of fly ash and normal concrete in this aspect is different. From rapid chloride permeability test, fly ash concrete under heat cure 3 ½ hours showed the immeasurably low resistance of chloride penetration. However, it was found that the heat effect influenced permeability development even when the heat source was removed. Different high temperature influenced hydration and pozzolanic reaction of fly ash concrete to different degree.

On the basis of the results and with consideration of proper flexible working schedule and feasibility of each method, both 75°C and 95°C promptly cured for 3 ½ hours was proposed as means for quality control and corrective measure. It was concluded that the relationship of accelerated and normal strength was statistically significant.