CHAPTER 5.

ENGINEERING PROPERTIES

5.1 MORTAR PROPERTIES

5.1.1 TEST PROGRAMS AND MIX PROPORTIONS

In this research, ordinary portland cement type I (Red Elephant Brand) according to ASTM C-150 was used in the amount of 500 kg/cement mortar volume 1 cu.m. Admixture type G - High range water reducing and retarding (Daracem-100) according to ASTM C-494 was used to improve workability in the amount of 6.7% by weight of cement. River sand from Karnchanaburi province was used as fine aggregate in the amount of 1,000 kg. Fineness modulus of sand was 2.7-2.9. Water to cementitious ratio was 0.32 constant.

Variables of tests are as follow,

1. At cement constant 1,000 g., the amount of expansive agent varies from 0, 1, 3, 5, 10 and 15% addition by weight of cement.

2. At cementitious (Cement and fly ash) constant, the amount of fly ash varies from 15, 20, 25 and 30% replacement by weight of cementitious.

3. At cement and expansive agent addition of 1, 5, 10 and 15%, the amount of fly ash varies from 15, 20, 25 and 30% replacement by weight of cementitious each.

The mix proportions of cement mortar are shown in table 5.1. Tests were carried out on mechanical and physical properties. Tests on mechanical property of the compressive strength were at 1, 3, 7, 14, 28, 56 and 91 days. Tests on the physical properties were water adsorption at 28 days and on shrinkage were at 1, 3, 7, 28, 42 and 56 days. The test schedule is shown in table 5.2.

5.1.2 PHYSICAL PROPERTIES

DRYING SHRINKAGE AND EXPANSION

The specimens for drying shrinkage tests were prepared according to ASTM C-490 (Use of Apparatus for The Determination of Length Change of Hardened Cement Paste, Mortar and Concrete) and ASTM C-596 (Measuring The Drying Shrinkage of Mortar Containing Portland Cement). The specimens were removed from water at the age of 3 days. The drying shrinkage readings were carried out at the ages of 1, 3, 7, 14, 21, 28, 42 and 56 days. The specimens were cured in the air room until the reading time. The average room temperature was 30°C (28°C minimum and 35°C maximum) and the average relative humidity was 80% (70% minimum and 85% maximum). Plastic shrinkage was protected by cover fresh mixture with a plastic sheet.

Table 5.3 and figures 5.1-5.4 show the test results of shrinkage and expansion of the mixtures. Shrinkage of ordinary portland cement mortar is −729 microstrain at 28 days while with addition of an expansive agent 1-15% by weight of cement, shrinkage reduced to −74 and −705 microstrain at 28 days. In the mixture with fly ash replacement 15-30% by weight of cement, shrinkage is reduced from −369 to −609 microstrain at 28 days.

The drying shrinkage of ordinary cement mortar increased until the age of 42 days and became constant. When the expansive agent was mixed with portland cement, the shrinkage reduced due to ettringite from the hydration reaction of calcium sulfoaluminate. The magnitude of expansion increased when the amount of expansive agent was increased. As the expansive agent increases by 10%, the expansion of cement mortar increases approximately by 80%.

In the paste with fly ash replacement, shrinkage was reduced due to the effect of cement replacement with non-expansive materials but fly ash also replaced the expansive agent in the mixture. The magnitude of shrinkage mostly depends on the effects of the reduction in cement. Increasing the amount of fly ash in the mixture by 10% tends to reduced shrinkage 15-20%.

WATER ADSORPTION

The test of water adsorption was carried out by mixing cement mortar according to table 5.1. After 1 day the specimens were demolded and immersed in water for 28 days. The specimens were removed from water and measured as initial weight. Then the specimens were dried in an oven at a temperature of 105°C for 7 days and measured. Express results are based on the initial weight after removal from water storage at the age of 28 days.

The test results are shown in table 5.4 and figures 5.5-5.6. Water adsorption of portland cement mortar with expansive agent varied from 9.9 to 11.47%. In a mixture with fly ash replacement 15-30% by weight of cement, water adsorption of cement mortars is reduced from 9.59 to 8.54%. Minimum adsorption is obtained from the paste with 30% fly ash replacement.

The weight of water loss on drying increased when the amount of expansive agent was increased. Because the paste contains more expansive agent, more ettringite is formed and this ettringite can absorb large amounts of water on its surface.

When cement was replaced with fly ash, water loss on drying was less than with ordinary portland cement mortar because fly ash makes the paste denser and filled pores due to the pozzolanic reaction. Then the water in pores is reduced. The magnitude of water loss decreases by 15-20% while fly ash increases by 10%.

5.1.3 MECHANICAL PROPERTIES

COMPRESSIVE STRENGTH

The specimens of cement mortar were prepared by using a 5x5x5 cm mold. After 1 day the specimens were demolded and immersed in water. Compressive strength tests were carried out at the ages of 1, 3, 7, 14, 28, 56 and 91 days. The specimens were cured in the water until the testing time and removed from water before test 1 day. Compressive strength was tested according to ASTM C-109 (Compressive Strength of Hydraulic Cement Mortars, Using 2 in. or 50 mm. Cube Specimens)

The maximum compressive strength of mortar is obtained from a mixture of portland cement with 15% expansive agent, that is 503 ksc. at 28 days. The compressive strength of mortar with the expansive agent 1-15% varied from 487 ksc. to 503 ksc. In a mixture with fly ash replacement 15 to 30%, the compressive strength was 503 ksc. to 424 ksc. at 28 days. The test results are shown in table 5.5 and figures 5.7-5.10.

The compressive strength of cement mortars with an expansive agent increased compared with ordinary portland cement mortar because the empty voids were filled with a hydrated compound from calcium sulphoaluminate. There was little difference between the compressive strength of the paste when the amount of expansive agent was increased.

When cement was replaced with fly ash, compressive strength gradually increased in later ages, because of the pozzolanic reaction of fly ash starting in later age. The compressive strength of 15% fly ash replacement was more than ordinary portland cement, because CaO in fly ash is highly reactive and produces more CSH in the paste. Increasing the amount of fly ash replacement tends to reduce compressive strength. The paste with 30% fly ash replacement gives the lowest strength. The magnitude of strength reduction was 10-15% as the amount of fly ash increased by 10%.

5.2 CONCRETE PROPERTIES

5.2.1 TEST PROGRAMS AND MIX PROPORTIONS

In this research, ordinary portland cement type I (Red Elephant Brand) according to ASTM C-150 was used in an amount of 500 kg/concrete 1 cu.m. Admixture type G - High range water reducing and retarding (Daracem-100) according to ASTM C-494 was used to improve workability in the amount of 8% by weight of cement. River sand from Karnchanaburi province was used as fine aggregate in the amount of 830 kg. Fineness modulus of sand was 2.7-2.9. Limestone as course aggregate in the amount of 1,025 kg./concrete 1 cu.m. was used. The maximum size of course aggregate was 1/2" from Saraburi province. Water to cementitious ratio was 0.32 constant.

Variables of tests are as follows ;

1. At cement constant 1,000 g., the amount of expansive agent varied from 0, 1, 3, 5, 10 and 15% addition by weight of cement.

2. At cementitious (Cement and fly ash) constant, the amount of fly ash varied from 15, 20, 25 and 30% replacement by weight of cementitious.

3. At cement and expansive agent addition of 1, 5, 10 and 15%, the amount of fly ash varied from 15, 20, 25 and 30% replacement by weight of cementitious each.

The mix proportions of concrete are shown in table 5.6. Tests were carried out on its mechanical and physical properties. Tests on its mechanical property as compressive strength were carried out at 1, 3, 7, 14, 28, 56 and 91 days. Tests on its physical properties were slump, flow, water adsorption and on shrinkage were at 1, 3, 7, 28, 42 and 56 days. The test schedule is shown in table 5.7.

5.2.2 PHYSICAL PROPERTIES

DRYING SHRINKAGE AND EXPANSION

The specimens for drying shrinkage tests were prepared according to ASTM C-490 (Use of Apparatus for The Determination of Length Change of Hardened Cement Paste, Mortar and Concrete) . The specimens were removed from water at the age of 3 days. The drying shrinkage readings were carried out at the ages of 1, 3, 7, 14, 21, 28, 42 and 56 days. The specimens were cured in the air room until the reading time. Average room temperature was 30°C (28°C minimum and 35°C maximum) and the average relative humidity was 80% (70% minimum and 85% maximum). Plastic shrinkage was protected by cover fresh mixture with a plastic sheet.

Table 5.8 and figures 5.11 to 5.14 show the results of shrinkage and expansion of the mixture. Shrinkage of ordinary portland concrete is -296 microstrain at 28 days. With the addition of an expansive agent 1-15% by weight of cement, shrinkage is reduced to -65 and -276 microstrain at 28 days. In the mixture with fly ash replacement 15-30% by weight of cement, shrinkage is reduced from -118 to -213 microstrain at 28 days. Figure 5.24 show the shrinkage of cement paste, mortar and concrete.

Drying shrinkage of ordinary cement concrete was slightly increased until the age of 21 days and became constant. After mixing the expansive agent with portland cement, the shrinkage was reduced due to ettringite from the hydration reaction of calcium sulfoaluminate. The increasing amount of expansive agent resulted in the increase of magnitude expansion with a 10% increase of expansive agent, the expansion of cement mortar approximately increased by 70%.

In the paste with fly ash replacement, shrinkage was reduced due to the effect of cement replacement with non-expansive materials but fly ash also replaced the expansive agent in the mixture. The magnitude of shrinkage mostly depends on the effects of a reduction in cement. Increasing the amount of fly ash in the mixture by 10% tends to reduce shrinkage by 10-15%.

WORKABILITY

Workability of concrete was tested by slump and flow tests. Tests of slump were carried out according to ASTM C-143 (Test Method for Slump of Hydraulic Cement Concrete). Slump tests measure the ability of concrete to resist its flow under its own weight and flow tests measure the ability of concrete to flow under jolting or continuous vibration and provide information regarding the tendency for segregation. The flow test was carried out according to AASHTO T-120 (Flow of Portland Cement Concrete by Use of the Flow Table)

Test results of slump and flow are shown in table 5.9 and figures 5.15-5.18. From the test results, slump of ordinary portland concrete is 24 cm. while flow is 55 cm. In the mixtures with an expansive agent 15% slump is reduced to 18 cm. In the mixture with 15-30% fly ash replacement, slump is 25-27 cm. while flow is 59-69 cm.

Increasing the amount of expansive agent tends to decrease the slump and flow because an expansive agent can absorb a large amount of water on its surface. This effect reduces free water from the mixture and makes concrete stiffer while replacing cement with an amount of fly ash will increase the slump and flow because the spherical shape of fly ash can increase the workability of concrete. Increasing the amount of fly ash resulted in an increasing slump and flow; increasing the amount of fly ash 10% in the mixture, slump and flow increases 10%.

WATER ADSORPTION

The test of water adsorption was carried out by mixing concrete according to table 5.1. After 1 day the specimens were demolded and immersed in water for 28 days. The specimens were removed from water and weighed as initial weight. Then the specimens were dried in an oven at a temperature of 105°C for 7 days and weight. Express results were based on the initial weight after removal from water storage at the age of 28 days.

The test results are shown in table 5.10 and figures 5.19-5.20. Water adsorption of concrete with an expansive agent varies from 5.10 to 6.14%. In a mixture with fly ash replacement 15-30% by weight of cement, water adsorption of concrete is reduced from 4.82 to 4.45%. Minimum adsorption is obtained from the paste with 30% fly ash replacement.

There was little difference in weight between the various types of specimens. This is probably due to limitations of specimen size and balance. The weight of water loss on drying increased when the amount of expansive agent increased because the paste contained more expansive agent, so more ettringite is formed and this ettringite can absorb large amounts of water on its surface.

When replacing cement with fly ash, water loss on drying was less than with ordinary portland concrete because fly ash makes the paste denser and filled pores due to the pozzolanic reaction. Then the water in pores will be reduced. The magnitude of water loss decreases 20% when fly ash is increased by 10%.

5.2.3 MECHANICAL PROPERTIES

COMPRESSIVE STRENGTH

The specimens of concrete were prepared by using 10x20 cm. cylinder molds. After 1 day the specimens were removed from the molds and stored in water according to ASTM C-192 (Making and curing concrete test specimens in the laboratory). The specimens were cured in the water until the testing time and removed from the water before testing time 1 day and capping according to ASTM C-617 (Capping cylinders). Compressive test of the cylindrical specimens was carried out according to ASTM C-39 (Test Method for Compressive Strength of Cylindrical Concrete Specimen). Compressive strength tests were carried out at the ages of 1, 3, 7, 14, 28, 56 and 91 days.

The maximum compressive strength of concrete obtained from the mixture of portland cement with 15% expansive agent was 713 ksc. at 28 days. The compressive strength of mortar with an expansive agent 1-15% varied from 705 ksc. to 751 ksc. In a mixture with fly ash replacement 15 to 30%, compressive strength was 607 ksc. to 768 ksc. at 28 days. The test results are shown in table 5.11 and figures 5.21-5.23.

Compressive strength of concrete with an expansive agent increased compared with ordinary portland concrete. Because the empty voids were filled with hydrated compound from calcium sulphoaluminate. There was little difference in the compressive strength of the paste when increasing the amount of expansive agent.

When cement was replaced with fly ash, compressive strength gradually increased because the pozzolanic reaction of fly ash starts in a later age. Compressive strength of 15% fly ash replacement was more than ordinary portland cement because CaO in fly ash is highly reactive and produces more CSH in the paste. Increasing the amount of fly ash replacement tends to reduce compressive strength. The magnitude of strength reduction was 10% while the amount of fly ash increased by 10%.

Table 5.1 Mix proportions of mortar

Mix No.	Net CE. (kg.)	Net. EX. (kg.)	FA (kg.)	Total Solid (kg.)	CE. (%)	EX. (%)	Fly Ash (%)	Fine Agg. (kg.)	W/S	Adm. (lts.)
M00-00	500	0	0	500	100.0	0.0	0.0	1000	0.32	6.7
M01-00	500	5	0	505	99.0	1.0	0.0	1000	0.32	6.7
M03-00	500	15	0	515	97.1	2.9	0.0	1000	0.32	6.7
M05-00	500	25	0	525	95.2	4.8	0.0	1000	0.32	6.7
M10-00	500	50	0	550	90.9	9.1	0.0	1000	0.32	6.7
M15-00	500	75	0	575	87.0	13.0	0.0	1000	0.32	6.7
M00-15	425	0	75	500	85.0	0.0	15.0	1000	0.32	6.7
M00-20	400	0	100	500	80.0	0.0	20.0	1000	0.32	6.7
M00-25	375	0	125	500	75.0	0.0	25.0	1000	0.32	6.7
M00-30	350	0	150	500	70.0	0.0	30.0	1000	0.32	6.7
M01-15	425	4	76	505	84.2	0.8	15.0	1000	0.32	6.7
M01-30	350	4	152	505	69.3	0.7	30.0	1000	0.32	6.7
M05-15	425	21	79	525	81.0	4.0	15.0	1000	0.32	6.7
M05-30	350	18	158	525	66.7	3.3	30.0	1000	0.32	6.7
M10-15	425	43	83	550	77.3	7.7	15.0	1000	0.32	6.7
M10-20	400	40	110	550	72.7	7.3	20.0	1000	0.32	6.7
M10-25	375	38	138	550	68.2	6.8	25.0	1000	0.32	6.7
M10-30	350	35	165	550	63.6	6.4	30.0	1000	0.32	6.7
M15-15	425	64	86	575	73.9	11.1	15.0	1000	0.32	6.7
M15-30	350	53	173	575	60.9	9.1	30.0	1000	0.32	6.7

Table 5.2 Test program for shrinkage compensating mortar

TYPES	EX. (%)	FA. (%)	Water Adsorbtion	Shrinkage and Expansion	Compressive Strength
1. Shrinkage Compensating Cement	0	-	M00-00	M00-00@1,3,7,14,28,42,56	M00-00@1,3,7,14,28,56,91
	1	-	M01-00	M01-00@1,3,7,14,28,42,56	M01-00@1,3,7,14,28,56,91
	3	-	M03-00	M03-00@1,3,7,14,28,42,56	M03-00@1,3,7,14,28,56,91
	5	-	M05-00	M05-00@1,3,7,14,28,42,56	M05-00@1,3,7,14,28,56,91
	10	-	M10-00	M10-00@1,3,7,14,28,42,56	M10-00@1,3,7,14,28,56,91
	15	-	M15-00	M15-00@1,3,7,14,28,42,56	M15-00@1,3,7,14,28,56,91
2. Shrinkage Compensating Cement with Fly Ash	-	15	M00-15	M00-15@1,3,7,14,28,42,56	M00-15@1,3,7,14,28,56,91
	-	20	M00-20	M00-20@1,3,7,14,28,42,56	M00-20@1,3,7,14,28,56,91
	-	25	M00-25	M00-25@1,3,7,14,28,42,56	M00-25@1,3,7,14,28,56,91
	-	30	M00-30	M00-30@1,3,7,14,28,42,56	M00-30@1,3,7,14,28,56,91
	1	15	M01-15	M01-15@1,3,7,14,28,42,56	M01-15@1,3,7,14,28,56,91
	1	30	M01-30	M01-30@1,3,7,14,28,42,56	M01-30@1,3,7,14,28,56,91
	5	15	M05-15	M05-15@1,3,7,14,28,42,56	M05-15@1,3,7,14,28,56,91
	5	30	M05-30	M05-30@1,3,7,14,28,42,56	M05-30@1,3,7,14,28,56,91
	10	15	M10-15	M10-15@1,3,7,14,28,42,56	M10-15@1,3,7,14,28,56,91
	10	20	M10-20	M10-20@1,3,7,14,28,42,56	M10-20@1,3,7,14,28,56,91
	10	25	M10-25	M10-25@1,3,7,14,28,42,56	M10-25@1,3,7,14,28,56,91
	10	30	M10-30	M10-30@1,3,7,14,28,42,56	M10-30@1,3,7,14,28,56,91
	15	15	M15-15	M15-15@1,3,7,14,28,42,56	M15-15@1,3,7,14,28,56,91
	15	30	M15-30	M15-30@1,3,7,14,28,42,56	M15-30@1,3,7,14,28,56,91

Table 5.3 Shrinkage and expansion of portland cement mortar

Mix No.	Shrinkage (Microstrain)							
	1	3	7	14	21	28	42	56
M00-00	-57	-96	-185	-413	-577	-729	-942	-1027
M01-00	14	-15	-139	-327	-540	-705	-907	-976
M03-00	22	55	-32	-163	-406	-529	-575	-634
M05-00	34	90	60	-105	-317	-377	-335	-349
M10-00	51	87	70	-40	-75	-100	-125	-120
M15-00	83	122	130	95	20	-15	-60	-75
M00-15	-30	-80	-150	-350	-475	-620	-790	-860
M00-20	-27	-60	-150	-330	-460	-573	-740	-805
M00-25	-30	-80	-155	-310	-420	-560	-697	-750
M00-30	-40	-70	-135	-290	-416	-504	-640	-700
M01-15	10	-16	-120	-280	-460	-590	-760	-810
M01-30	9	-7	-90	-225	-360	-470	-615	-670
M05-15	30	60	50	-80	-263	-300	-305	-310
M05-30	25	60	40	-70	-195	-224	-230	-230
M10-15	37	60	40	-25	-60	-80	-100	-100
M10-20	40	70	50	-25	-55	-75	-100	-90
M10-25	38	65	47	-30	-50	-70	-90	-90
M10-30	49	60	45	-27	-48	-65	-80	-84
M15-15	66	90	100	75	20	10	-45	-60
M15-30	52	74	85	65	17	6	-36	-47

Table 5.4 Water adsorbtion of shrinkage compensating mortar

Mix No.	CE. (kg.)	Ex. (%)	Ex. (kg.)	Fly Ash (%)	Fly Ash (kg.)	Total Solid (kg.)	W/S	Adm. (lts.)	Water Content (%)
M00-00	500	0	0	0	0	500	0.32	8.0	9.90
M01-00	500	1	10	0	0	510	0.32	8.0	10.11
M03-00	500	3	30	0	0	530	0.32	8.0	10.43
M05-00	500	5	50	0	0	550	0.32	8.0	10.69
M10-00	500	10	100	0	0	600	0.32	8.0	11.17
M15-00	500	15	150	0	0	650	0.32	8.0	11.47
M00-15	425	0	0	15	75	500	0.32	8.0	9.59
M00-20	400	0	0	20	100	500	0.32	8.0	9.23
M00-25	375	0	0	25	125	500	0.32	8.0	8.74
M00-30	350	0	0	30	150	500	0.32	8.0	8.54
M01-15	425	1	9	15	77	510	0.32	8.0	9.73
M01-30	350	1	7	30	153	510	0.32	8.0	8.74
M05-15	425	5	43	15	83	550	0.32	8.0	10.21
M05-30	350	5	35	30	165	550	0.32	8.0	9.34
M10-15	425	10	85	15	90	600	0.32	8.0	10.69
M10-20	400	10	80	20	120	600	0.32	8.0	10.34
M10-25	375	10	75	25	150	600	0.32	8.0	9.89
M10-30	350	10	70	30	180	600	0.32	8.0	9.56
M15-15	425	15	128	15	98	650	0.32	8.0	10.86
M15-30	350	15	105	30	195	650	0.32	8.0	9.73

Table 5.5A Compressive strength of shrinkage compensating mortar

Mix No.	Compressive Strength (ksc.)						
	1	3	7	14	28	56	91
M00-00A	256	312	372	432	496	528	548
M00-00B	248	292	360	432	484	512	532
M00-00C	244	284	344	424	480	512	520
Avg.	**249**	**296**	**359**	**429**	**487**	**517**	**533**
M01-00A	260	304	384	440	504	540	544
M01-00B	252	300	360	436	492	528	540
M01-00C	248	300	360	428	480	512	540
Avg.	**253**	**301**	**368**	**435**	**492**	**527**	**541**
M05-00A	276	332	384	472	528	544	556
M05-00B	260	308	380	456	504	544	552
M05-00C	260	304	364	448	500	528	544
Avg.	**265**	**315**	**376**	**459**	**511**	**539**	**551**
M10-00A	292	324	412	476	540	556	580
M10-00B	272	316	372	464	528	552	568
M10-00C	260	312	380	448	492	548	560
Avg.	**275**	**317**	**388**	**463**	**520**	**552**	**569**
M15-00A	288	348	412	484	548	584	600
M15-00B	276	320	388	472	544	560	580
M15-00C	268	316	380	460	520	560	572
Avg.	**277**	**328**	**393**	**472**	**537**	**568**	**584**
M00-15A	240	324	376	452	508	560	580
M00-15B	228	320	380	440	500	540	572
M00-15C	220	296	360	420	500	528	528
Avg.	**229**	**313**	**372**	**437**	**503**	**543**	**560**

Table 5.5B Compressive strength of shrinkage compensating mortar

Mix No.	Compressive Strength (ksc.)						
	1	3	7	14	28	56	91
M00-20A	228	312	348	424	488	520	552
M00-20B	228	288	344	408	480	512	536
M00-20C	208	268	340	400	464	508	528
Avg.	**221**	**289**	**344**	**411**	**477**	**513**	**539**
M00-25A	232	268	328	400	472	500	520
M00-25B	212	260	308	388	448	484	512
M00-25C	208	240	296	380	440	480	512
Avg.	**217**	**256**	**311**	**389**	**453**	**488**	**515**
M00-30A	224	252	304	364	440	472	488
M00-30B	212	248	292	360	408	452	480
M00-30C	200	240	280	348	424	448	468
Avg.	**212**	**247**	**292**	**357**	**424**	**457**	**479**
M01-15A	240	344	436	460	520	556	568
M01-15B	228	336	400	452	500	524	552
M01-15C	220	324	412	456	512	532	540
Avg.	**229**	**335**	**416**	**456**	**511**	**537**	**553**
M01-30A	232	272	304	368	440	480	492
M01-30B	212	248	280	360	432	464	484
M01-30C	216	244	280	344	420	448	464
Avg.	**220**	**255**	**288**	**357**	**431**	**464**	**480**
M05-15A	240	360	440	480	532	556	584
M05-15B	240	344	420	488	520	552	564
M05-15C	228	336	424	460	516	548	560
Avg.	**236**	**347**	**428**	**476**	**523**	**552**	**569**

Table 5.5C Compressive strength of shrinkage compensating mortar

Mix No.	Compressive Strength (ksc.)						
	1	3	7	14	28	56	91
M05-30A	232	280	312	384	452	480	504
M05-30B	224	260	280	372	440	480	492
M05-30C	224	240	280	368	428	456	480
Avg.	**227**	**260**	**291**	**375**	**440**	**472**	**492**
M10-15A	240	372	452	504	556	580	600
M10-15B	240	348	440	496	540	580	580
M10-15C	240	344	420	476	520	556	584
Avg.	**240**	**355**	**437**	**492**	**539**	**572**	**588**
M10-30A	260	280	320	400	460	500	520
M10-30B	240	260	304	384	448	480	500
M10-30C	224	272	300	372	440	476	504
Avg.	**241**	**271**	**308**	**385**	**449**	**485**	**508**
M15-15A	260	380	464	512	584	600	620
M15-15B	248	360	452	508	544	580	596
M15-15C	244	348	428	492	532	560	560
Avg.	**251**	**363**	**448**	**504**	**553**	**580**	**592**
M15-30A	240	280	344	412	476	512	520
M15-30B	240	280	324	400	460	496	508
M15-30C	240	272	312	384	444	488	516
Avg.	**240**	**277**	**327**	**399**	**460**	**499**	**515**

Table 5.6 Mix proportions of concrete

Mix No.	Net CE. (kg.)	Net. EX. (kg.)	FA (kg.)	Total Solid (kg.)	CE. (%)	EX. (%)	FA. (%)	Fine Agg(kg.)	Course Agg(kg.)	W/S	Adm. (lts.)
C00-00	500	0	0	500	100.0	0.0	0.0	830	1025	0.32	8.0
C01-00	500	5	0	505	99.0	1.0	0.0	830	1025	0.32	8.0
C03-00	500	15	0	515	97.1	2.9	0.0	830	1025	0.32	8.0
C05-00	500	25	0	525	95.2	4.8	0.0	830	1025	0.32	8.0
C10-00	500	50	0	550	90.9	9.1	0.0	830	1025	0.32	8.0
C15-00	500	75	0	575	87.0	13.0	0.0	830	1025	0.32	8.0
C00-15	425	0	75	500	85.0	0.0	15.0	830	1025	0.32	8.0
C00-20	400	0	100	500	80.0	0.0	20.0	830	1025	0.32	8.0
C00-25	375	0	125	500	75.0	0.0	25.0	830	1025	0.32	8.0
C00-30	350	0	150	500	70.0	0.0	30.0	830	1025	0.32	8.0
C01-15	425	4	76	505	84.2	0.8	15.0	830	1025	0.32	8.0
C01-30	350	4	152	505	69.3	0.7	30.0	830	1025	0.32	8.0
C05-15	425	21	79	525	81.0	4.0	15.0	830	1025	0.32	8.0
C05-30	350	18	158	525	66.7	3.3	30.0	830	1025	0.32	8.0
C10-15	425	43	83	550	77.3	7.7	15.0	830	1025	0.32	8.0
C10-20	400	40	110	550	72.7	7.3	20.0	830	1025	0.32	8.0
C10-25	375	38	138	550	68.2	6.8	25.0	830	1025	0.32	8.0
C10-30	350	35	165	550	63.6	6.4	30.0	830	1025	0.32	8.0
C15-15	425	64	86	575	73.9	11.1	15.0	830	1025	0.32	8.0
C15-30	350	53	173	575	60.9	9.1	30.0	830	1025	0.32	8.0

Table 5.7 Test program for shrinkage compensating concrete

TYPES	EX. (%)	FA. (%)	Water Adsorbtion	Flow and Slump	Shrinkage and Expansion	Compressive Strength
1. Shrinkage Compensating Cement	0	-	C00-00	C00-00	C00-00@1,3,7,14,28,42,56	C00-00@1,3,7,14,28,56,91
	1	-	C01-00	C01-00	C01-00@1,3,7,14,28,42,56	C01-00@1,3,7,14,28,56,91
	3	-	C03-00	C03-00	C03-00@1,3,7,14,28,42,56	C03-00@1,3,7,14,28,56,91
	5	-	C05-00	C05-00	C05-00@1,3,7,14,28,42,56	C05-00@1,3,7,14,28,56,91
	10	-	C10-00	C10-00	C10-00@1,3,7,14,28,42,56	C10-00@1,3,7,14,28,56,91
	15	-	C15-00	C15-00	C15-00@1,3,7,14,28,42,56	C15-00@1,3,7,14,28,56,91
2. Shrinkage Compensating Cement with Fly Ash	-	15	C00-15	C00-15	C00-15@1,3,7,14,28,42,56	C00-15@1,3,7,14,28,56,91
	-	20	C00-20	C00-20	C00-20@1,3,7,14,28,42,56	C00-20@1,3,7,14,28,56,91
	-	25	C00-25	C00-25	C00-25@1,3,7,14,28,42,56	C00-25@1,3,7,14,28,56,91
	-	30	C00-30	C00-30	C00-30@1,3,7,14,28,42,56	C00-30@1,3,7,14,28,56,91
	1	15	C01-15	C01-15	C01-15@1,3,7,14,28,42,56	C01-15@1,3,7,14,28,56,91
	1	30	C01-30	C01-30	C01-30@1,3,7,14,28,42,56	C01-30@1,3,7,14,28,56,91
	5	15	C05-15	C05-15	C05-15@1,3,7,14,28,42,56	C05-15@1,3,7,14,28,56,91
	5	30	C05-30	C05-30	C05-30@1,3,7,14,28,42,56	C05-30@1,3,7,14,28,56,91
	10	15	C10-15	C10-15	C10-15@1,3,7,14,28,42,56	C10-15@1,3,7,14,28,56,91
	10	20	C10-20	C10-20	C10-20@1,3,7,14,28,42,56	C10-20@1,3,7,14,28,56,91
	10	25	C10-25	C10-25	C10-25@1,3,7,14,28,42,56	C10-25@1,3,7,14,28,56,91
	10	30	C10-30	C10-30	C10-30@1,3,7,14,28,42,56	C10-30@1,3,7,14,28,56,91
	15	15	C15-15	C15-15	C15-15@1,3,7,14,28,42,56	C15-15@1,3,7,14,28,56,91
	15	30	C15-30	C15-30	C15-30@1,3,7,14,28,42,56	C15-30@1,3,7,14,28,56,91

Table 5.8 Shrinkage and expansion of concrete

Mix No.	Shrinkage (Microstrain)							
	1	3	7	14	21	28	42	56
C00-00	-258	-269	-278	-286	-291	-296	-300	-298
C01-00	-230	-250	-258	-262	-270	-276	-284	-281
C03-00	-180	-190	-190	-200	-220	-220	-230	-230
C05-00	-110	-120	-130	-141	-145	-160	-161	-161
C10-00	-25	-30	-55	-68	-66	-75	-75	-90
C15-00	30	35	25	-10	-25	-30	-40	-45
C00-15	-220	-225	-230	-240	-246	-250	-253	-250
C00-20	-205	-210	-220	-228	-230	-235	-236	-240
C00-25	-188	-195	-200	-206	-215	-220	-220	-220
C00-30	-182	-188	-193	-199	-200	-202	-203	-200
C01-15	-192	-200	-207	-217	-220	-228	-235	-230
C01-30	-158	-166	-178	-176	-180	-185	-188	-186
C05-15	-90	-97	-106	-115	-124	-129	-128	-130
C05-30	-70	-76	-87	-93	-99	-106	-107	-106
C10-15	-35	-45	-47	-55	-55	-60	-65	-75
C10-20	-30	-40	-48	-51	-52	-57	-60	-70
C10-25	-28	-38	-40	-50	-50	-55	-57	-70
C10-30	-28	-35	-37	-49	-48	-50	-50	-67
C15-15	25	30	23	-8	-19	-25	-30	-39
C15-30	20	28	20	-6	-16	-20	-29	-30

Table 5.9 Slump and flow of shrinkage compensating concrete

Mix No.	CE. (kg.)	Ex. (%)	Ex. (kg.)	Fly Ash (%)	Fly Ash (kg.)	Total Solid (kg.)	W/S	Adm. (lts.)	Slump (cm.)	Flow (cm.)
C00-00	500	0	0	0	0	500	0.32	8.0	24	55
C01-00	500	1	10	0	0	510	0.32	8.0	24	55
C03-00	500	3	30	0	0	530	0.32	8.0	24	54
C05-00	500	5	50	0	0	550	0.32	8.0	22	52
C10-00	500	10	100	0	0	600	0.32	8.0	21	49
C15-00	500	15	150	0	0	650	0.32	8.0	18	45
C00-15	425	0	0	15	75	500	0.32	8.0	25	59
C00-20	400	0	0	20	100	500	0.32	8.0	25	62
C00-25	375	0	0	25	125	500	0.32	8.0	26	65
C00-30	350	0	0	30	150	500	0.32	8.0	27	69
C01-15	425	1	9	15	77	510	0.32	8.0	25	57
C01-30	350	1	7	30	153	510	0.32	8.0	27	68
C05-15	425	5	43	15	83	550	0.32	8.0	24	56
C05-30	350	5	35	30	165	550	0.32	8.0	26	65
C10-15	425	10	85	15	90	600	0.32	8.0	22	51
C10-20	400	10	80	20	120	600	0.32	8.0	22	60
C10-25	375	10	75	25	150	600	0.32	8.0	23	61
C10-30	350	10	70	30	180	600	0.32	8.0	24	62
C15-15	425	15	128	15	98	650	0.32	8.0	19	48
C15-30	350	15	105	30	195	650	0.32	8.0	21	54

Table 5.10 Water adsorbtion of shrinkage compensating concrete

Mix No.	CE. (kg.)	Ex. (%)	Ex. (kg.)	Fly Ash (%)	Fly Ash (kg.)	Total Solid (kg.)	W/S	Adm. (lts.)	Water Content (%)
C00-00	500	0	0	0	0	500	0.32	8.0	5.07
C01-00	500	1	10	0	0	510	0.32	8.0	5.10
C03-00	500	3	30	0	0	530	0.32	8.0	5.15
C05-00	500	5	50	0	0	550	0.32	8.0	5.36
C10-00	500	10	100	0	0	600	0.32	8.0	5.92
C15-00	500	15	150	0	0	650	0.32	8.0	6.14
C00-15	425	0	0	15	75	500	0.32	8.0	4.82
C00-20	400	0	0	20	100	500	0.32	8.0	4.70
C00-25	375	0	0	25	125	500	0.32	8.0	4.51
C00-30	350	0	0	30	150	500	0.32	8.0	4.45
C01-15	425	1	9	15	77	510	0.32	8.0	4.89
C01-30	350	1	7	30	153	510	0.32	8.0	4.50
C05-15	425	5	43	15	83	550	0.32	8.0	5.12
C05-30	350	5	35	30	165	550	0.32	8.0	4.77
C10-15	425	10	85	15	90	600	0.32	8.0	5.60
C10-20	400	10	80	20	120	600	0.32	8.0	5.28
C10-25	375	10	75	25	150	600	0.32	8.0	5.08
C10-30	350	10	70	30	180	600	0.32	8.0	5.08
C15-15	425	15	128	15	98	650	0.32	8.0	5.73
C15-30	350	15	105	30	195	650	0.32	8.0	5.18

Table 5.11A Compressive strength of shrinkage compensating concrete

Mix No.	Compressive Strength (ksc.)						
	1	3	7	14	28	56	91
C00-00A	306	509	547	624	649	713	777
C00-00B	293	484	522	611	649	688	738
C00-00C	267	420	522	586	649	688	764
Avg.	**289**	**471**	**531**	**607**	**649**	**696**	**760**
C01-00A	306	497	586	637	700	726	764
C01-00B	306	484	522	611	649	700	738
C01-00C	293	471	535	611	637	688	726
Avg.	**301**	**484**	**547**	**620**	**662**	**705**	**743**
C05-00A	344	535	586	649	700	751	802
C05-00B	306	509	573	637	675	713	764
C05-00C	318	471	535	624	675	713	751
Avg.	**323**	**505**	**564**	**637**	**683**	**726**	**772**
C10-00A	344	522	598	662	700	751	789
C10-00B	318	522	586	662	688	738	789
C10-00C	306	522	573	637	700	726	777
Avg.	**323**	**522**	**586**	**654**	**696**	**738**	**785**
C15-00A	344	573	611	688	726	764	802
C15-00B	331	522	598	662	713	751	789
C15-00C	318	522	573	637	700	738	789
Avg.	**331**	**539**	**594**	**662**	**713**	**751**	**794**
C00-15A	344	484	624	713	789	853	891
C00-15B	331	471	611	688	764	828	866
C00-15C	306	471	586	675	751	802	853
Avg.	**327**	**475**	**607**	**692**	**768**	**828**	**870**

Table 5.11B Compressive strength of shrinkage compensating concrete

Mix No.	Compressive Strength (ksc.)						
	1	3	7	14	28	56	91
C00-20A	318	509	637	700	751	815	815
C00-20B	318	509	611	688	726	789	815
C00-20C	306	497	598	675	700	764	802
Avg.	**314**	**505**	**615**	**688**	**726**	**789**	**811**
C00-25A	331	446	598	649	726	789	789
C00-25B	293	433	573	637	700	751	777
C00-25C	306	433	560	624	688	738	764
Avg.	**310**	**437**	**577**	**637**	**705**	**760**	**777**
C00-30A	280	369	471	547	624	675	738
C00-30B	255	344	420	522	611	675	713
C00-30C	255	331	420	509	586	649	700
Avg.	**263**	**348**	**437**	**526**	**607**	**666**	**717**
C01-15A	331	535	611	713	789	853	879
C01-15B	306	522	586	688	777	815	853
C01-15C	306	471	586	649	764	789	840
Avg.	**314**	**509**	**594**	**683**	**777**	**819**	**857**
C01-30A	255	382	484	573	637	713	726
C01-30B	255	344	458	547	611	662	688
C01-30C	255	357	433	522	586	675	688
Avg.	**255**	**361**	**458**	**547**	**611**	**683**	**700**
C05-15A	331	560	637	726	815	866	891
C05-15B	318	509	598	700	789	840	866
C05-15C	306	484	573	688	777	802	866
Avg.	**318**	**518**	**603**	**705**	**794**	**836**	**874**

Table 5.11C Compressive strength of shrinkage compensating concrete

Mix No.	Compressive Strength (ksc.)						
	1	3	7	14	28	56	91
C05-30A	255	395	497	598	662	713	777
C05-30B	242	382	458	560	637	700	726
C05-30C	242	357	446	535	598	675	700
Avg.	**246**	**378**	**467**	**564**	**632**	**696**	**734**
C10-15A	344	573	649	726	828	866	891
C10-15B	318	535	611	726	815	853	891
C10-15C	306	484	586	700	777	828	853
Avg.	**323**	**531**	**615**	**717**	**806**	**849**	**879**
C10-30A	280	382	522	598	688	726	764
C10-30B	255	382	471	560	637	713	751
C10-30C	242	382	458	547	611	688	726
Avg.	**259**	**382**	**484**	**569**	**645**	**709**	**747**
C15-15A	344	573	637	738	853	891	917
C15-15B	331	509	624	738	802	853	891
C15-15C	318	497	573	688	789	815	853
Avg.	**331**	**526**	**611**	**722**	**815**	**853**	**887**
C15-30A	306	420	547	598	675	738	802
C15-30B	242	382	484	586	637	726	764
C15-30C	229	382	458	547	637	700	738
Avg.	**259**	**395**	**497**	**577**	**649**	**722**	**768**

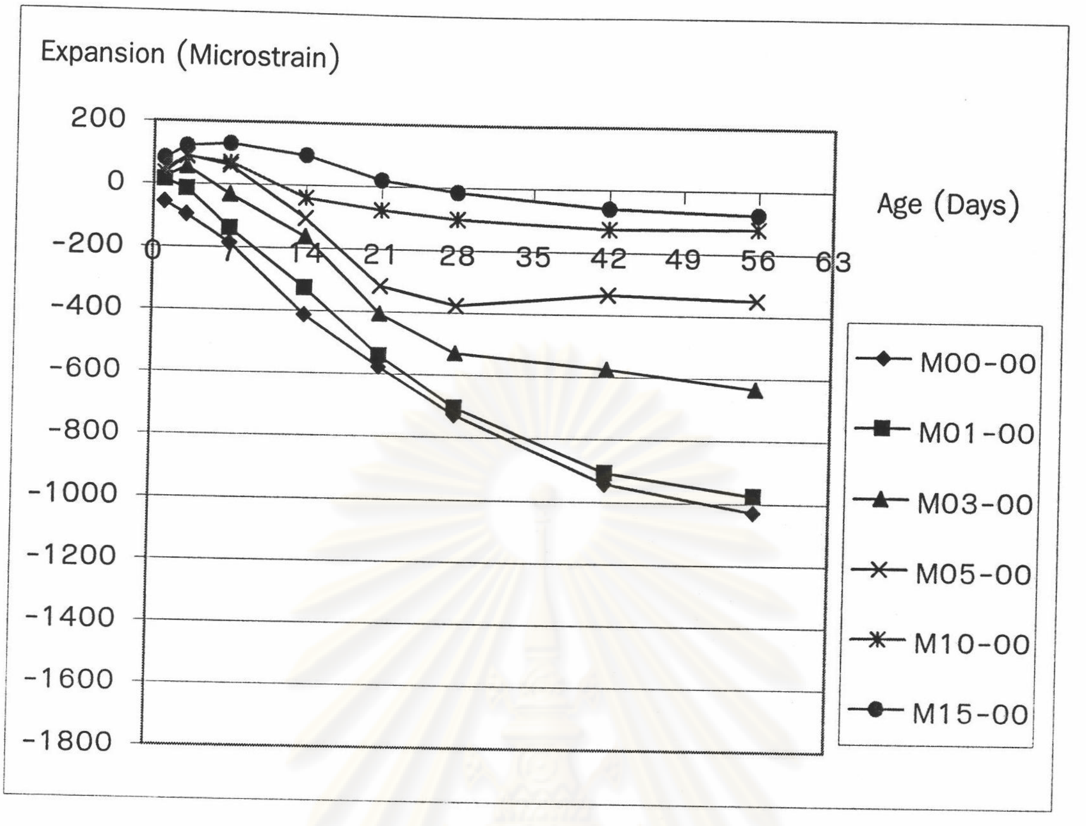

Fig. 5.1 Shrinkage of shrinkage compensating mortar

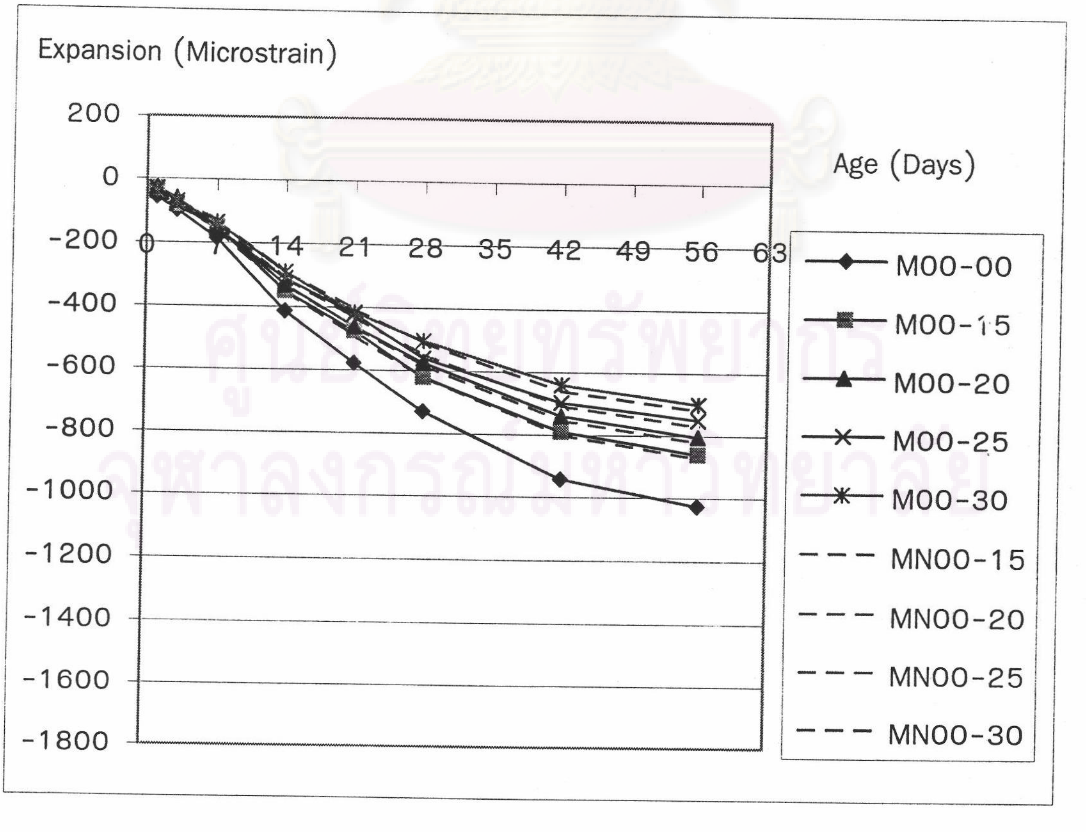

Fig. 5.2 Effects of fly ash in mortar

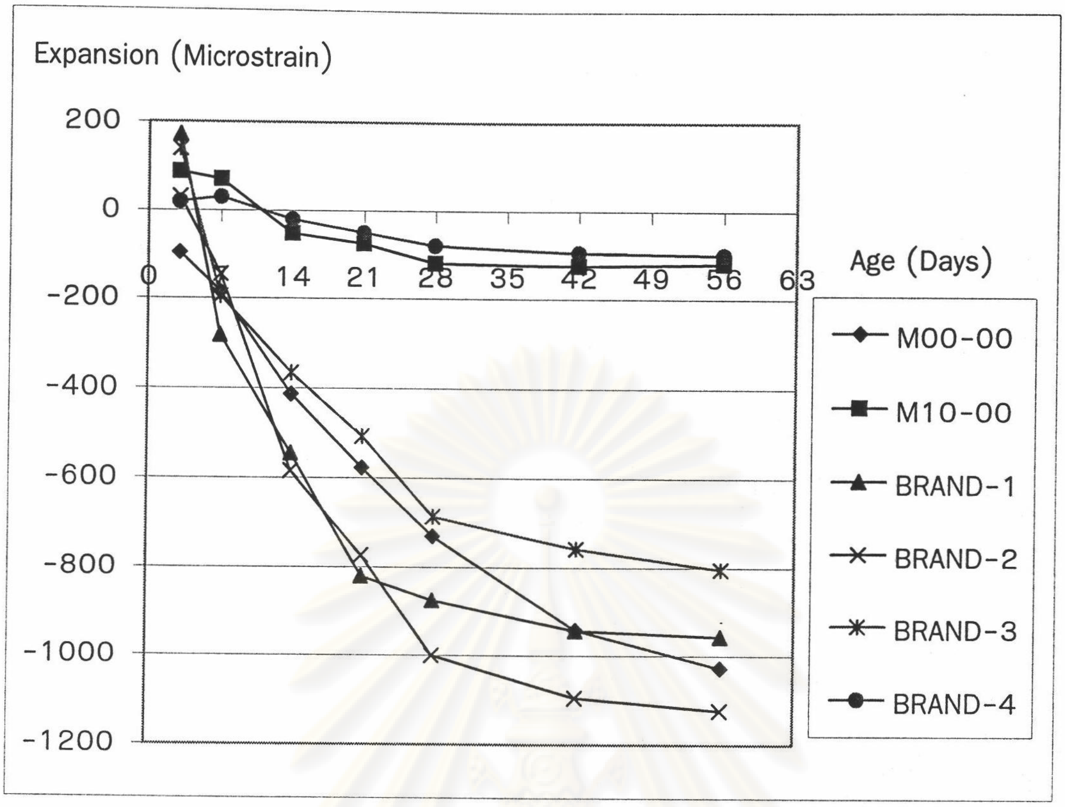

Fig. 5.3 Shrinkage of commercial grouting cement

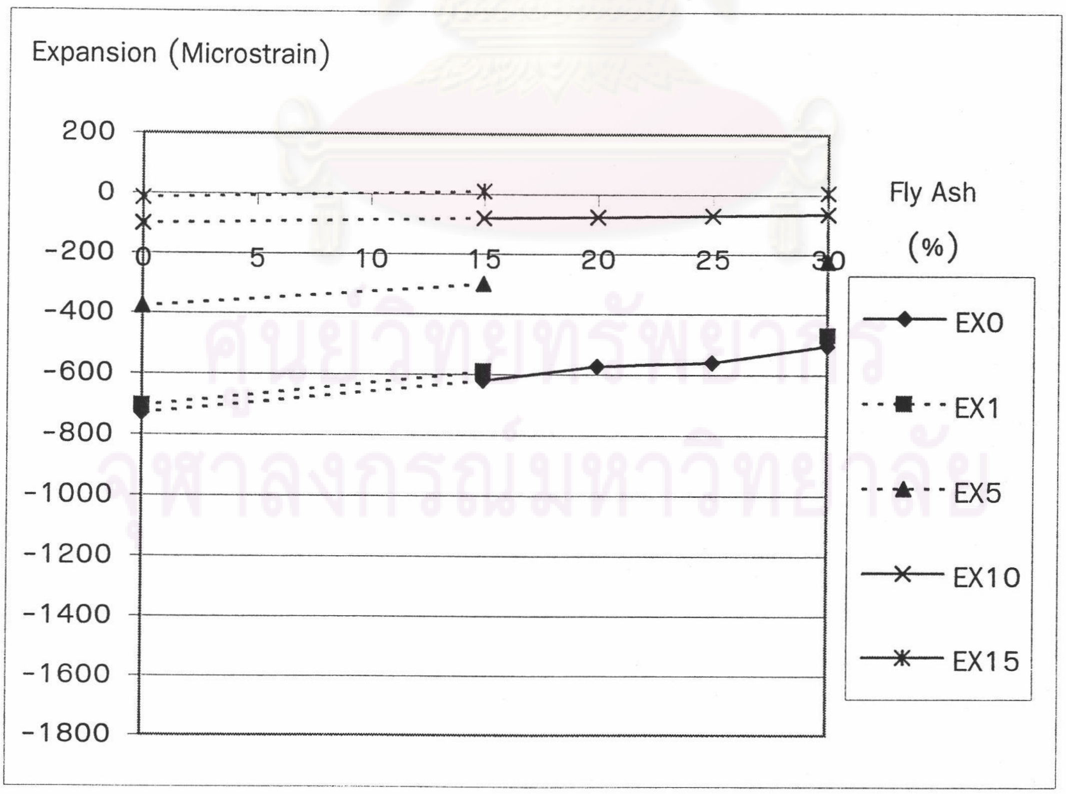

Fig. 5.4 Shrinkage of mortar by fly ash at 28 day

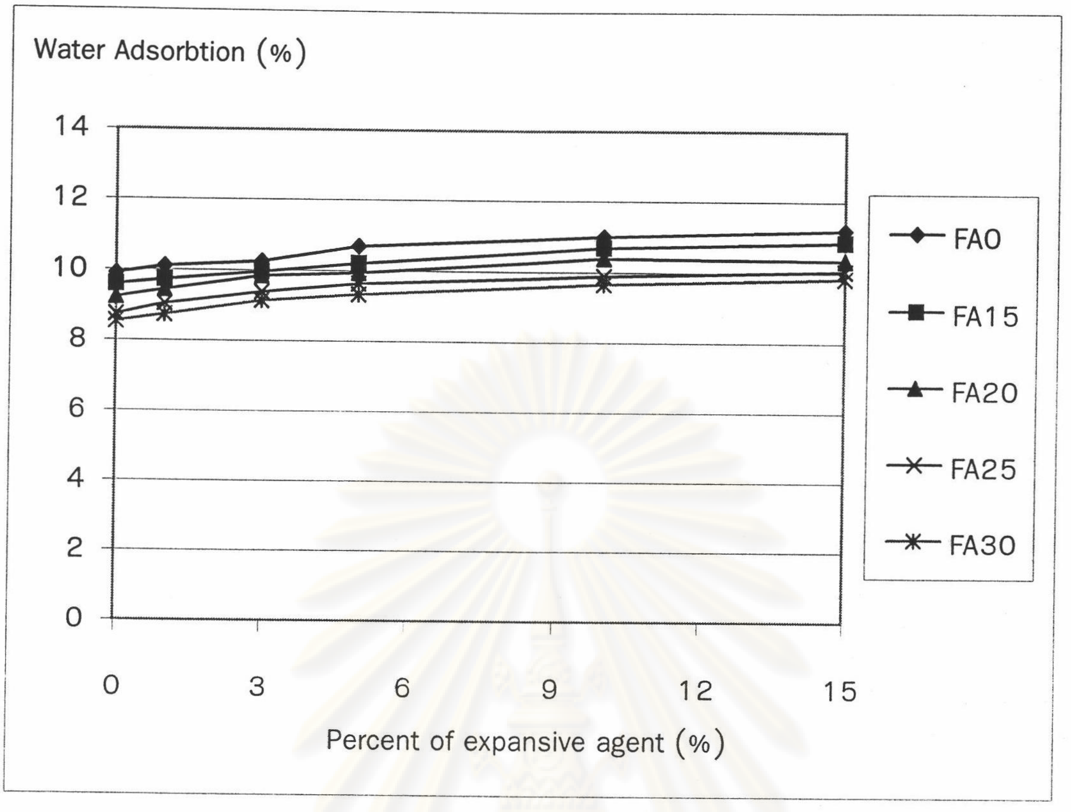

Fig. 5.5 Water adsorbtion of mortar by expansive agent

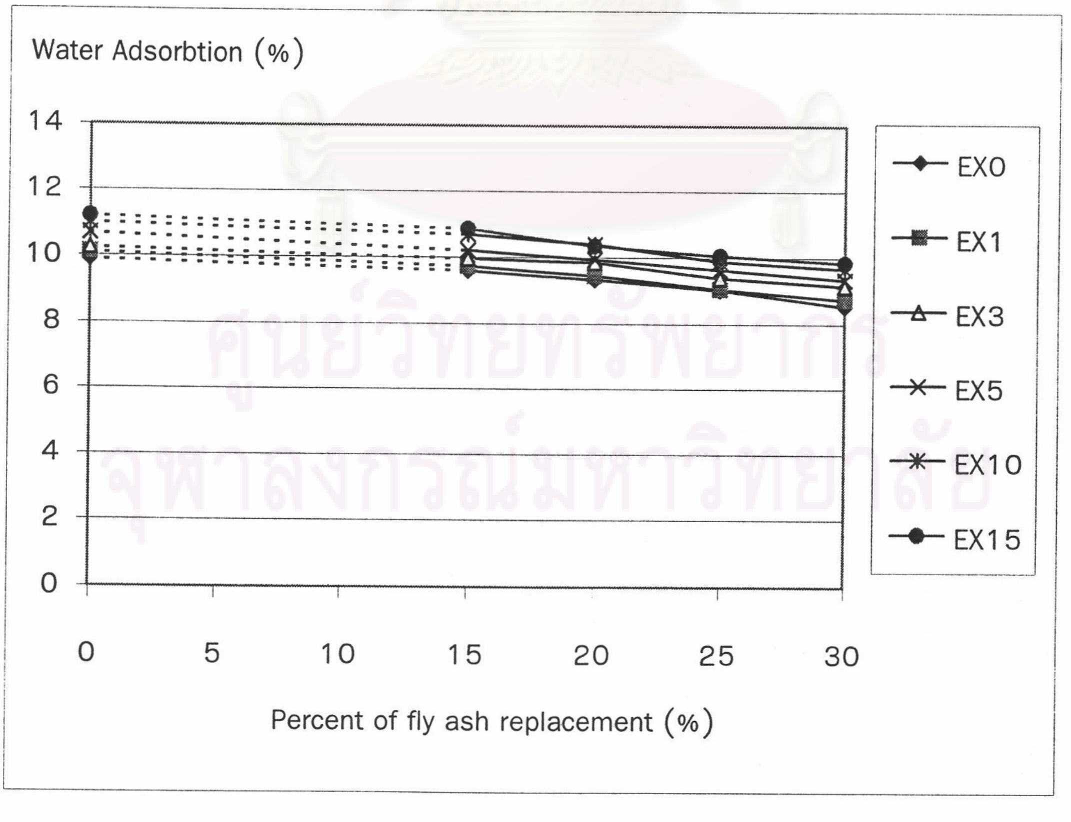

Fig. 5.6 Water adsorbtion of mortar by fly ash

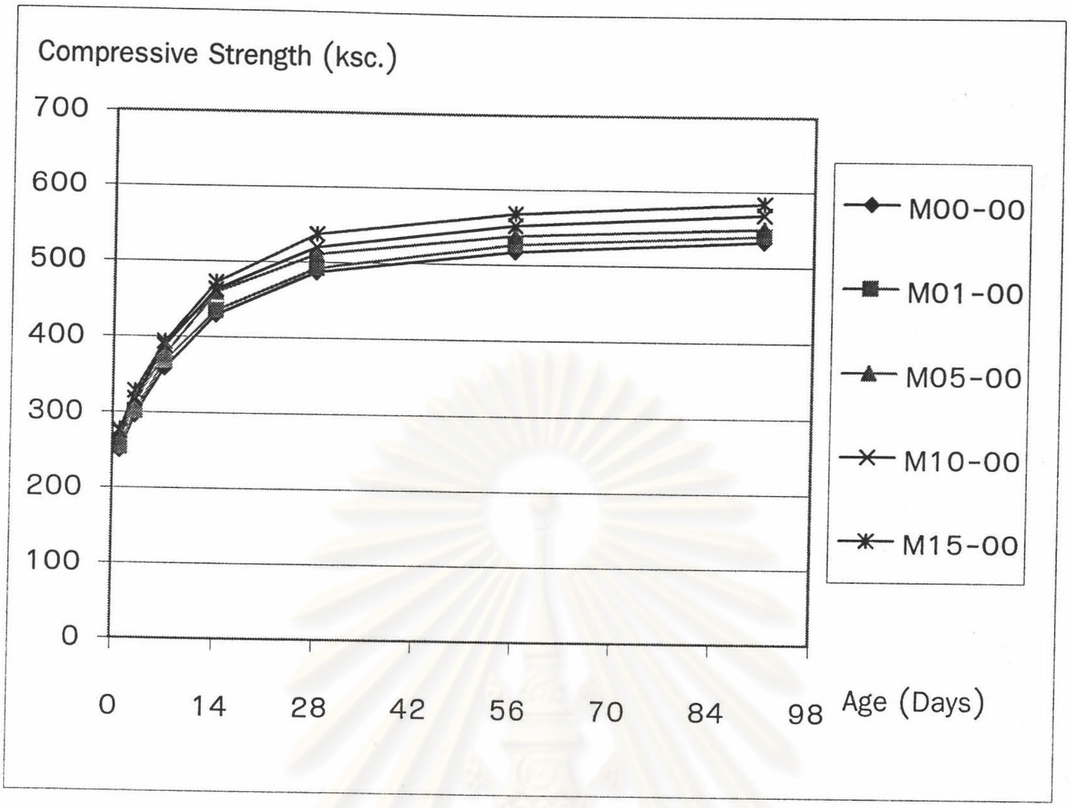

Fig. 5.7 Compressive strength of mortar by expansive agent

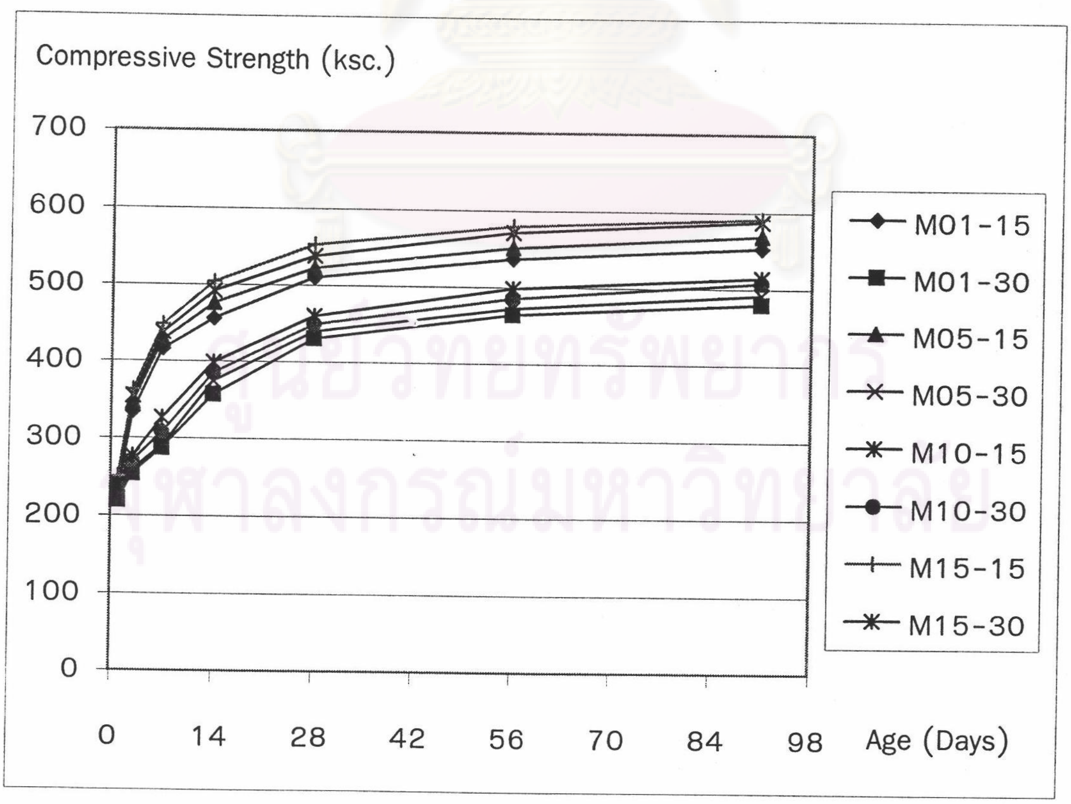

Fig. 5.8 Compressive strength of mortar by fly ash replacement

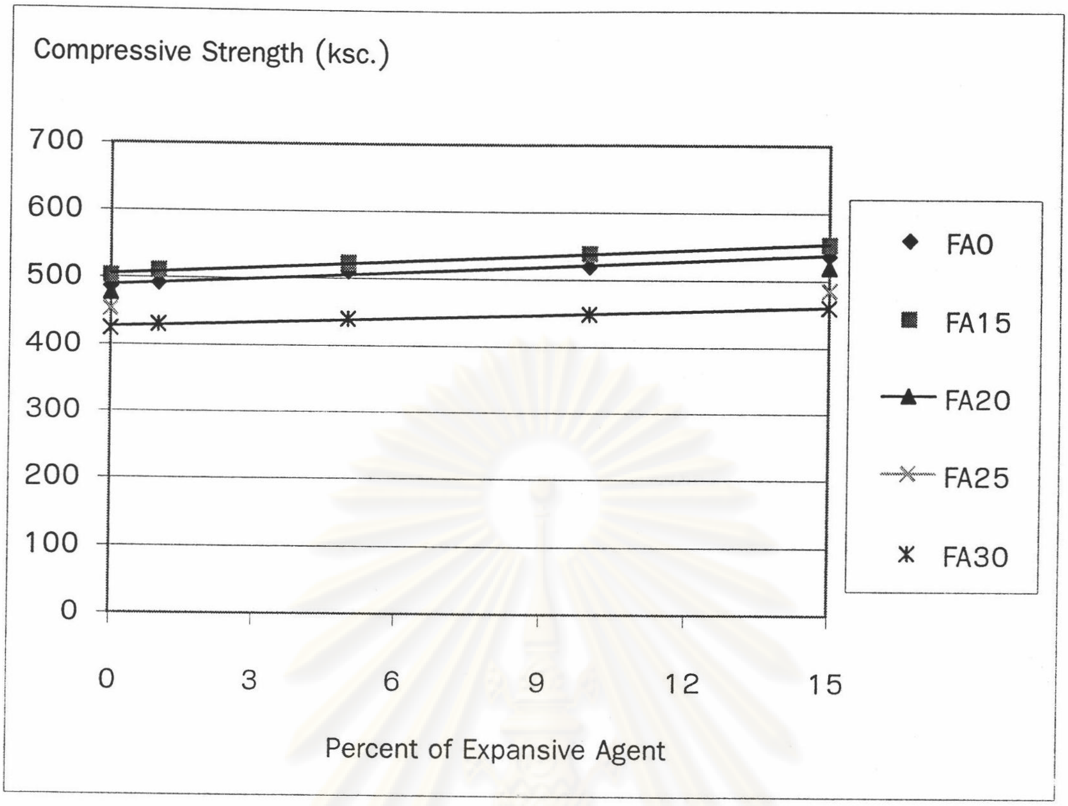

Fig. 5.9 Compressive strength of mortar by expansive agent

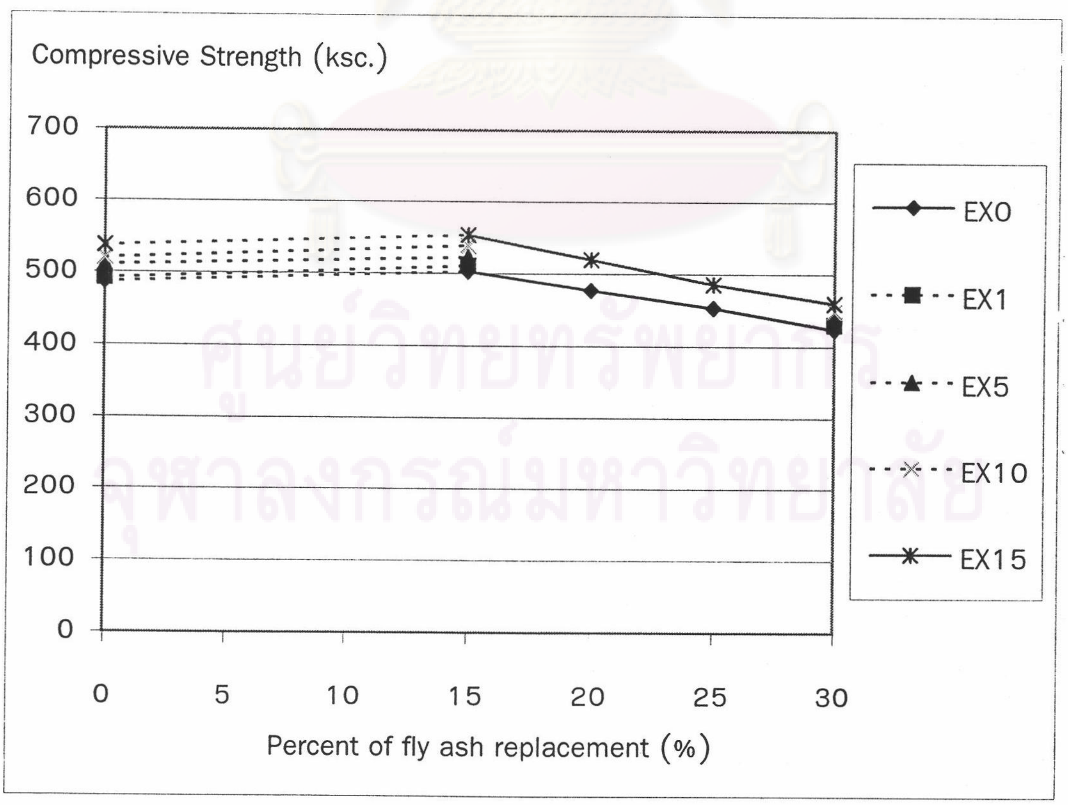

Fig. 5.10 Compressive strength of mortar of fly ash

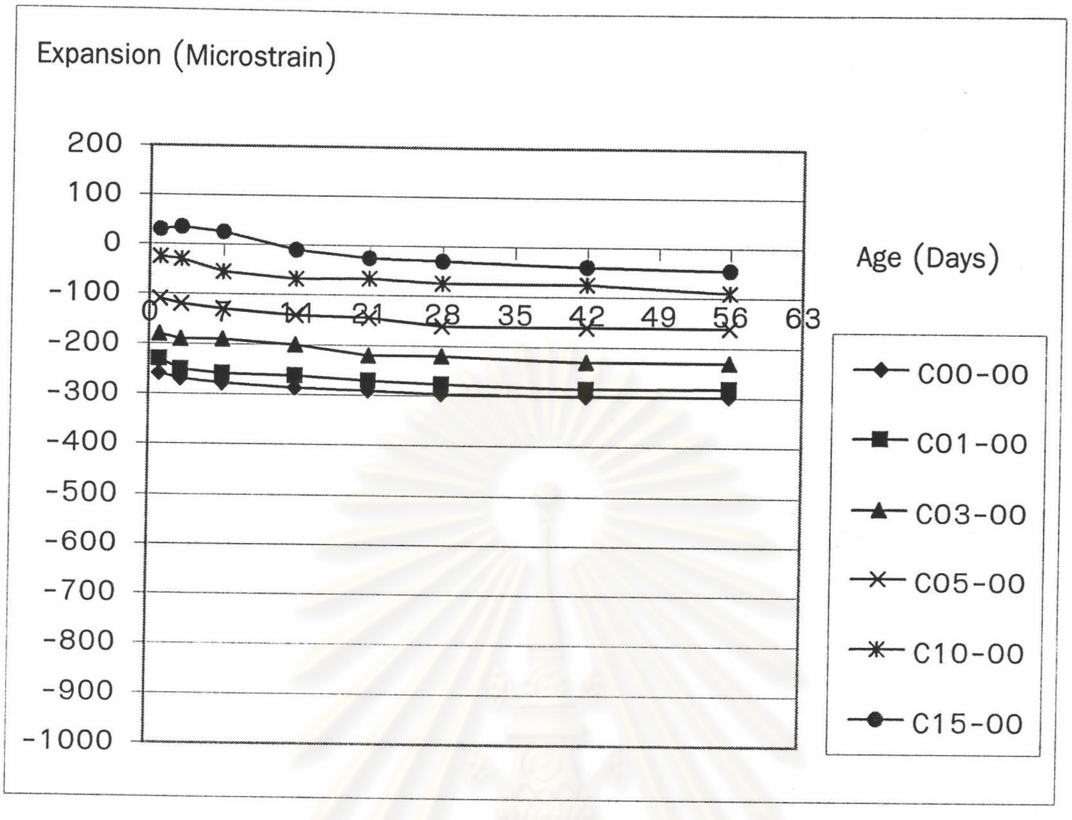

Fig. 5.11 Shrinkage of shrinkage compensating concrete

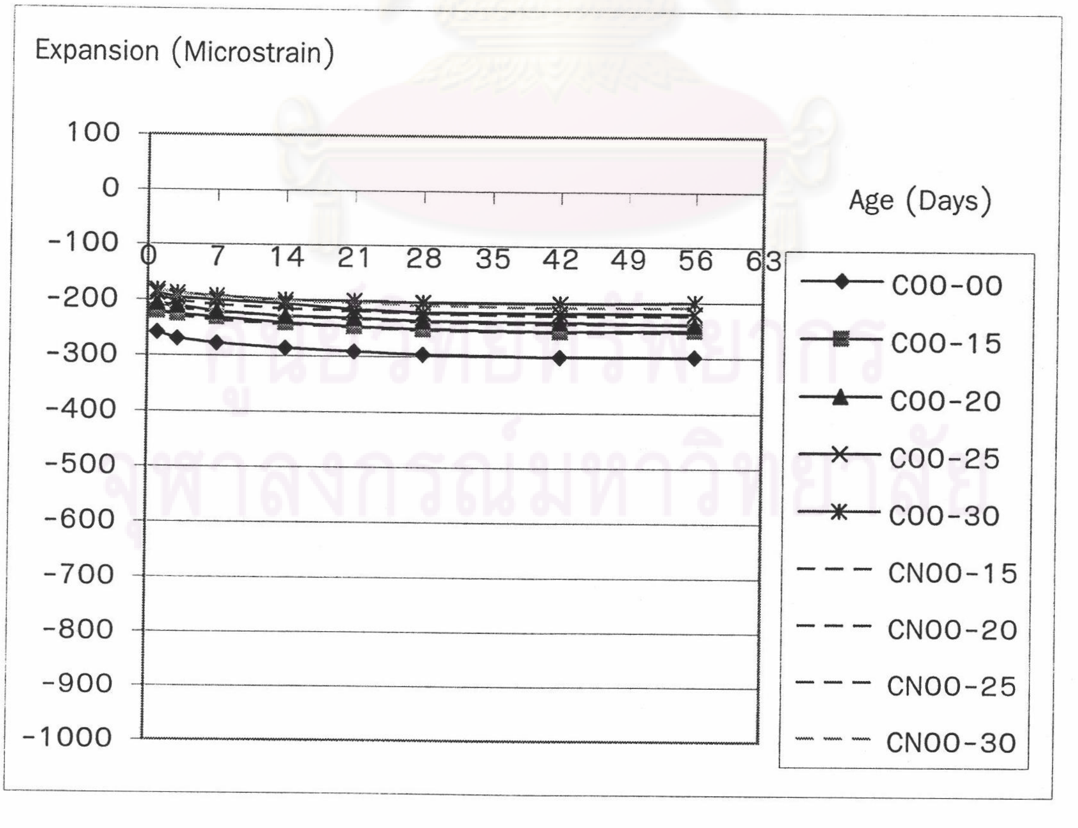

Fig. 5.12 Effects of fly ash in concrete

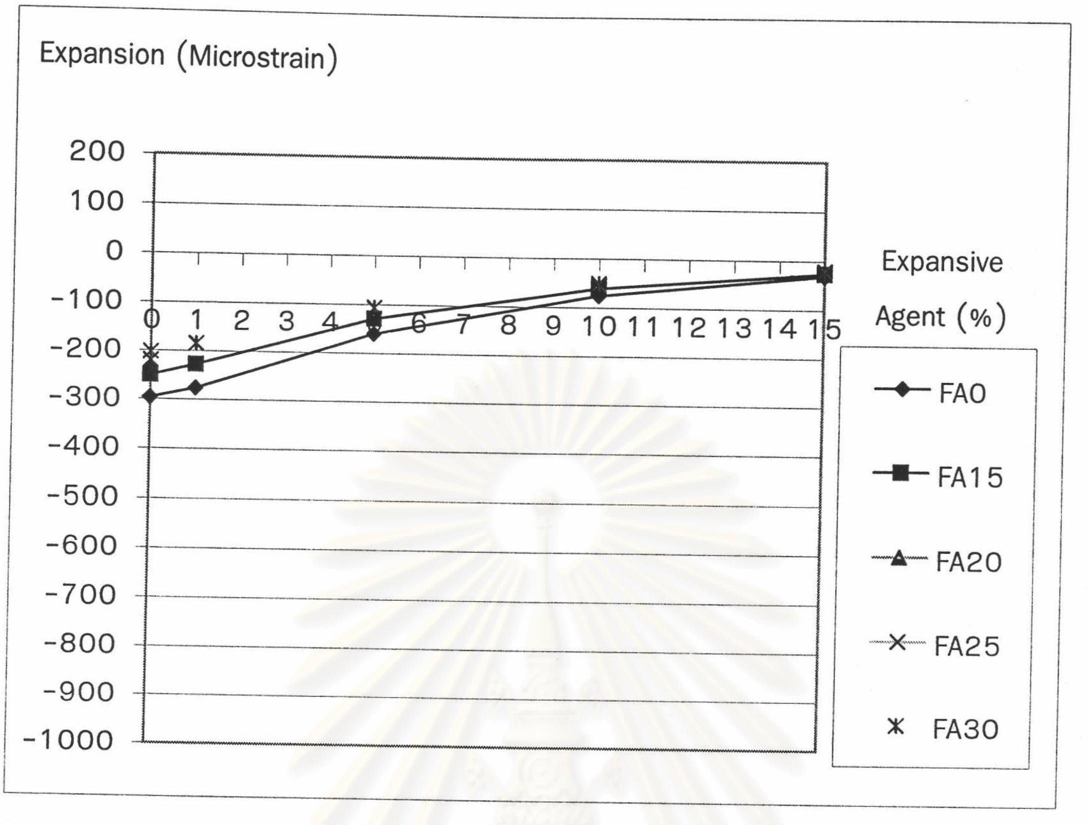

Fig. 5.13 Shrinkage of concrete by expansive agent

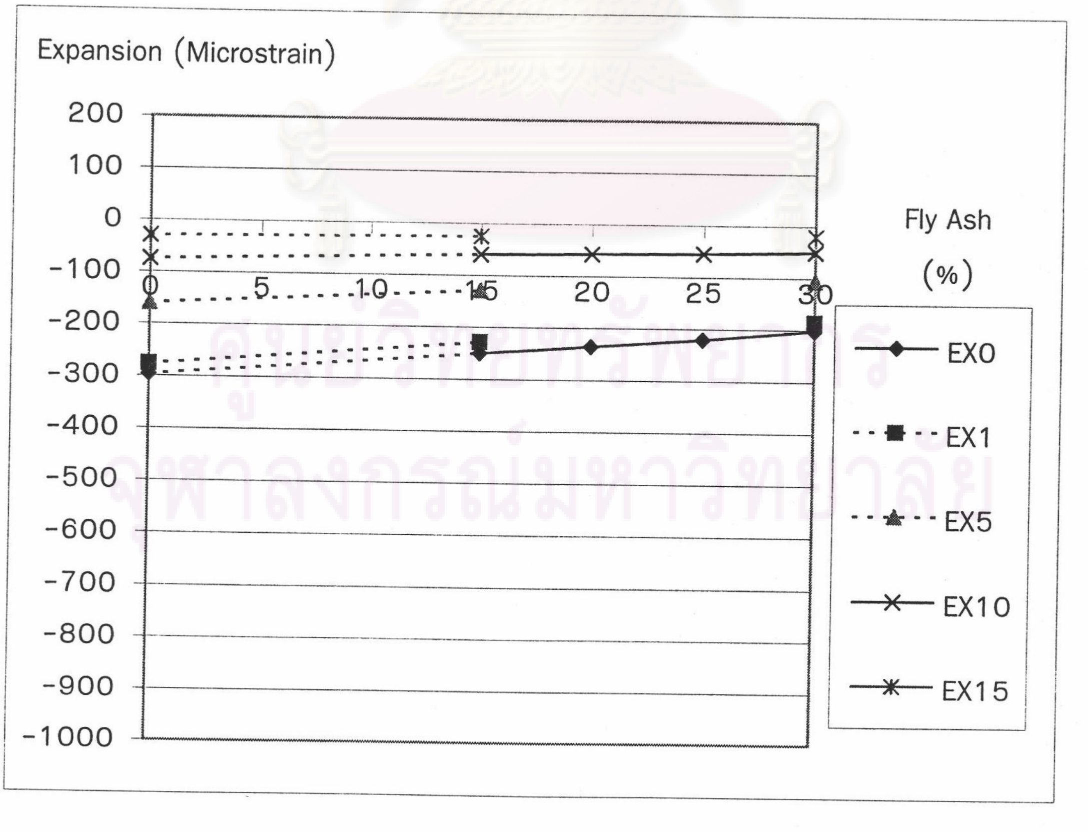

Fig. 5.14 Shrinkage of concrete by fly ash

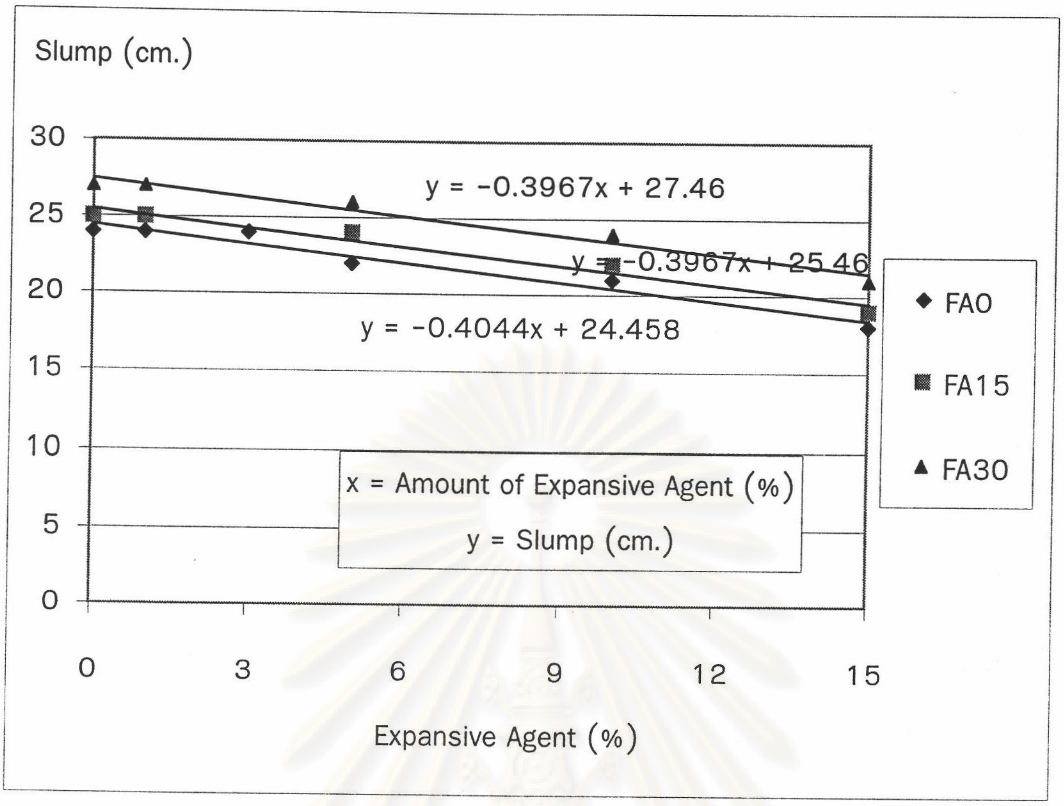

Fig. 5.15 Slump by percent of expansive agent

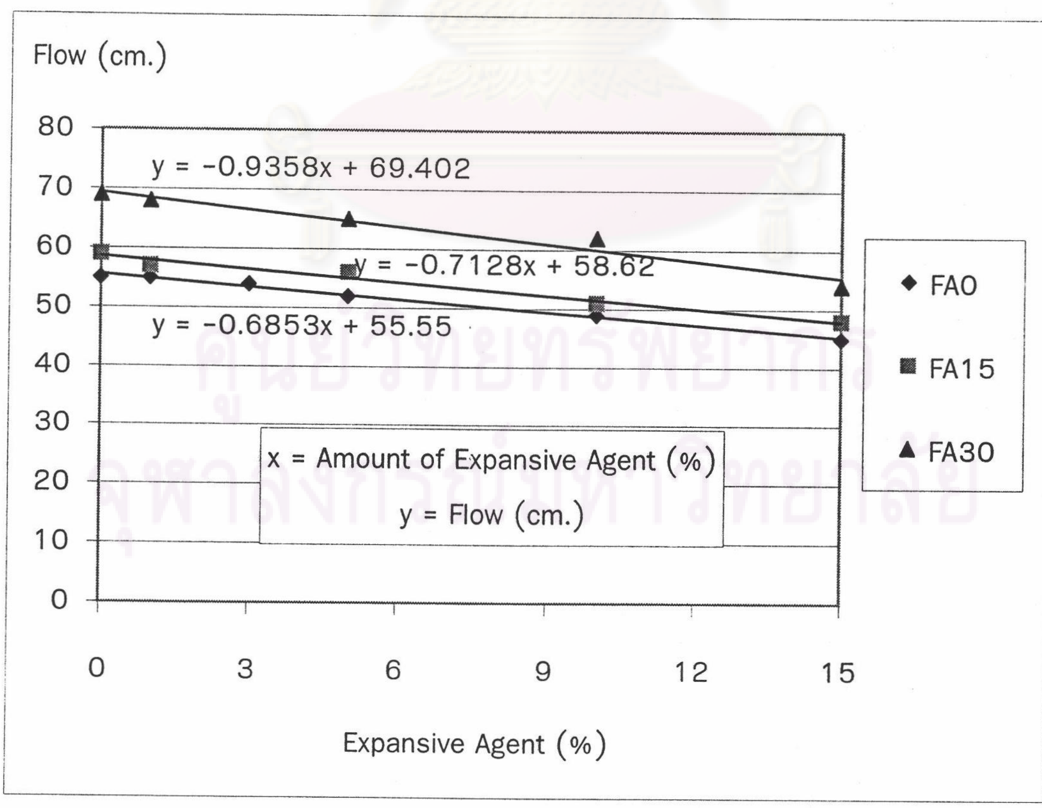

Fig 5.16 Flow by percent of expansive agent

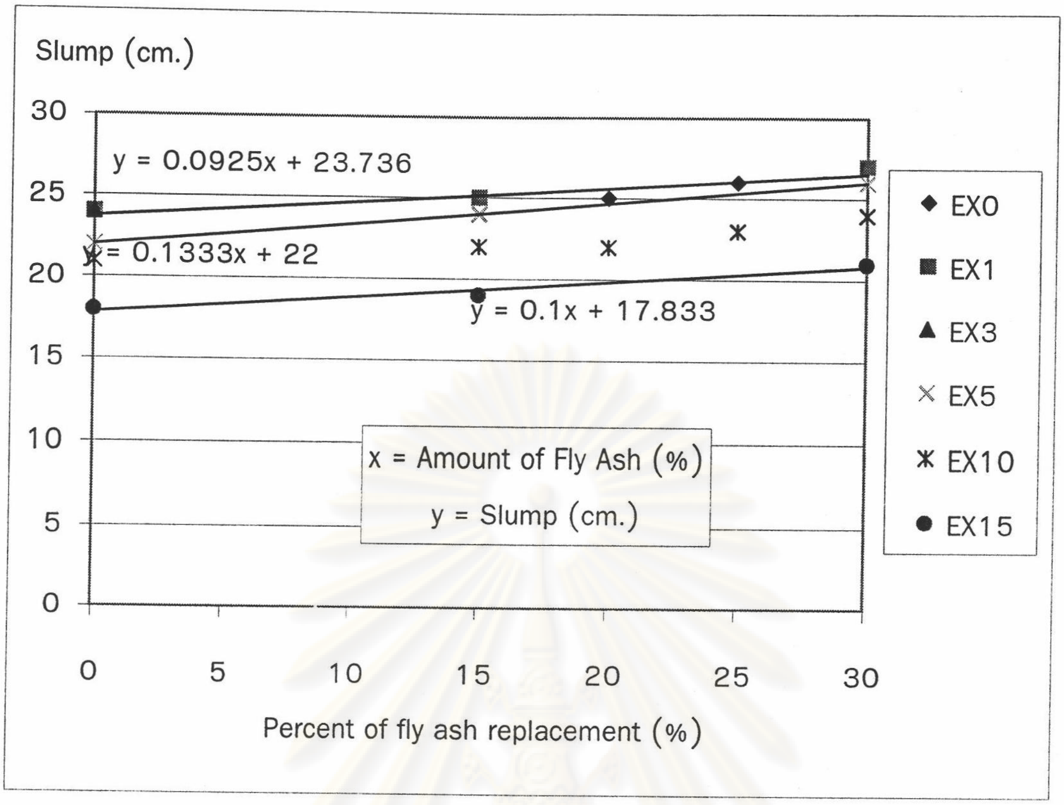

Fig 5.17 Slump by percent of fly ash

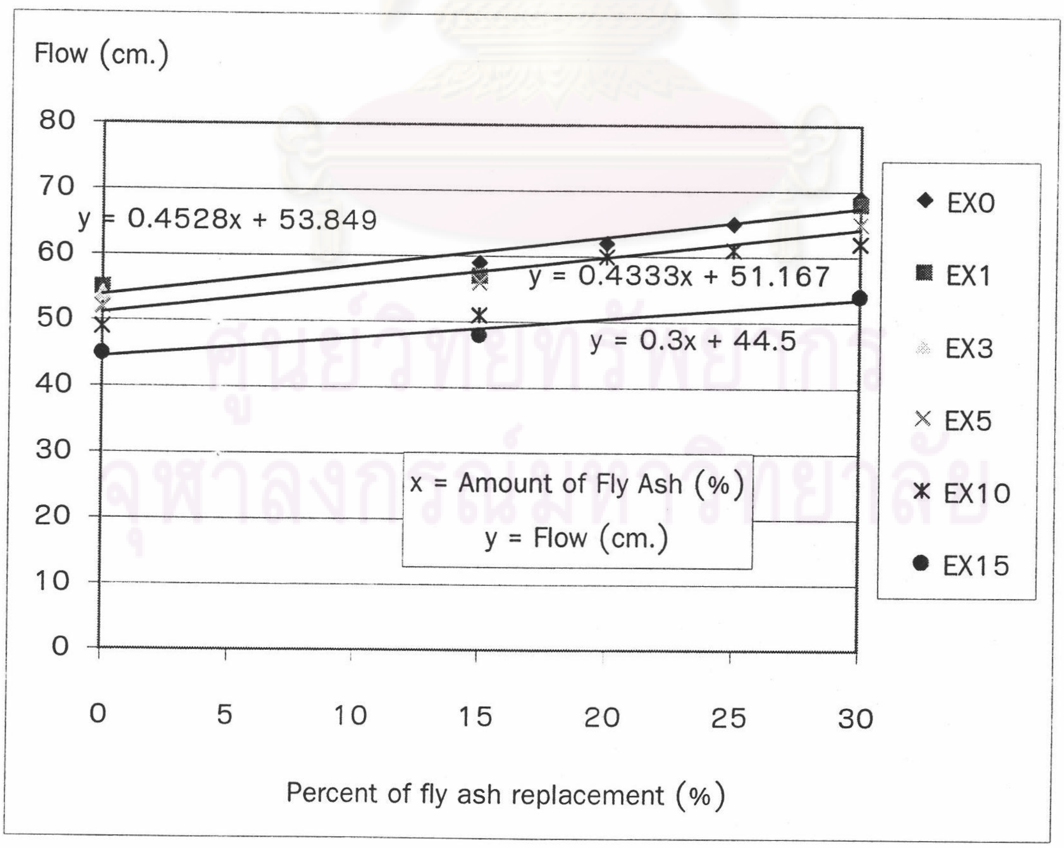

Fig 5.18 Flow by percent of fly ash

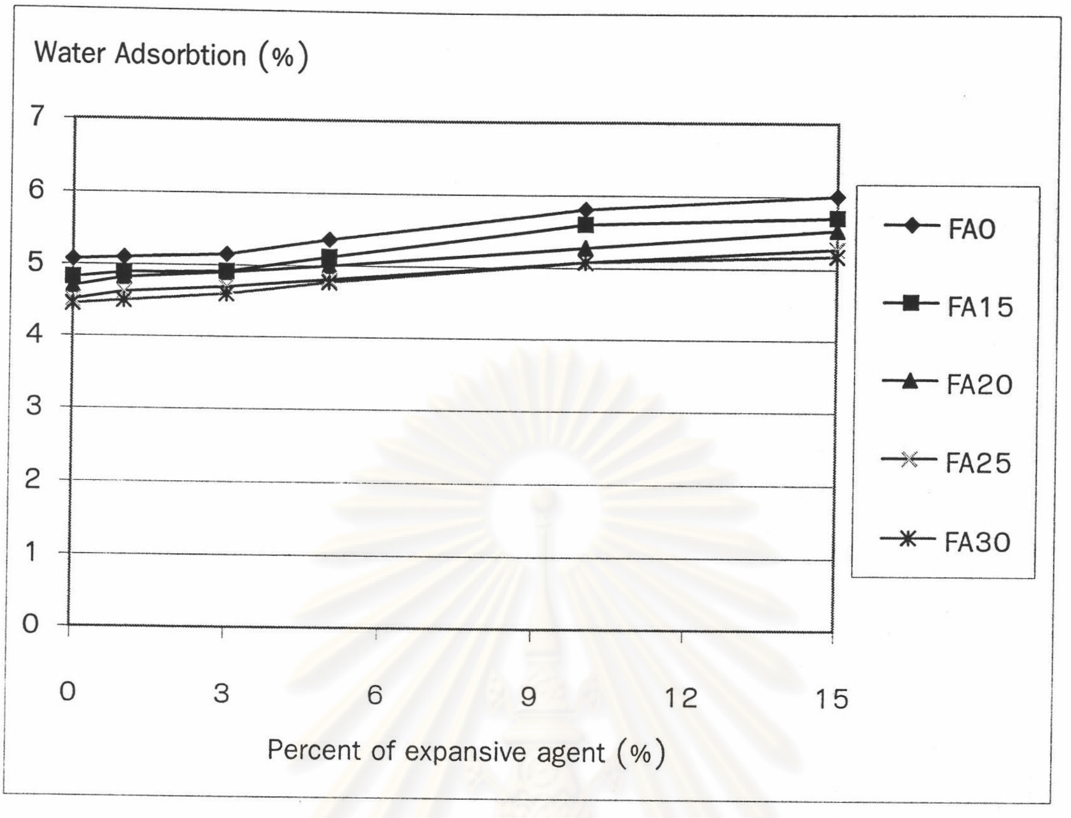

Fig. 5.19 Water adsorbtion of concrete by expansive agent

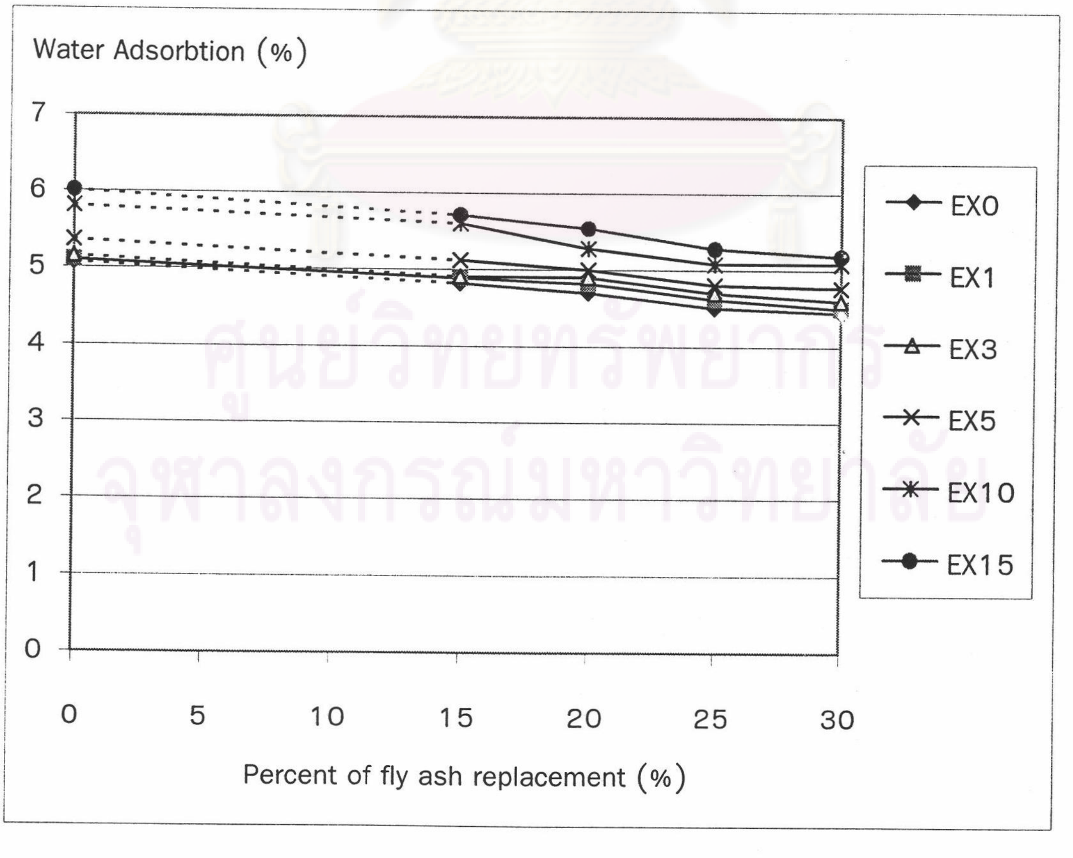

Fig. 5.20 Water adsorbtion of concrete by fly ash

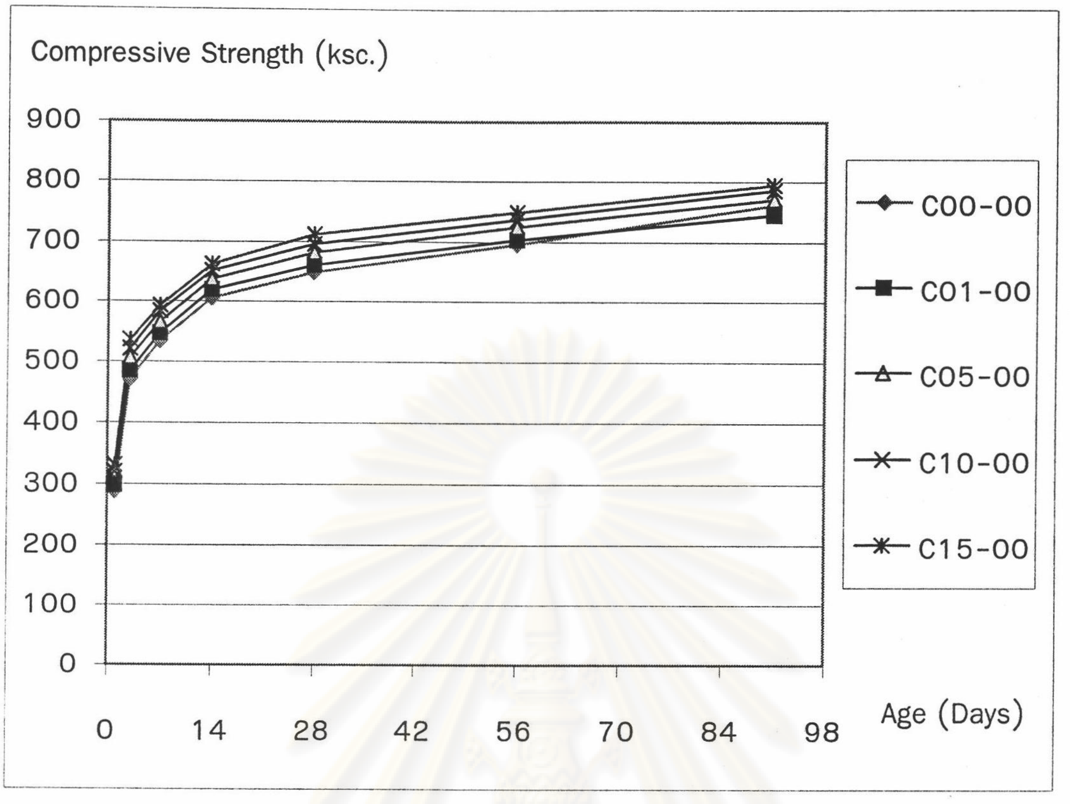

Fig. 5.21 Compressive strength of concrete by expansive agent

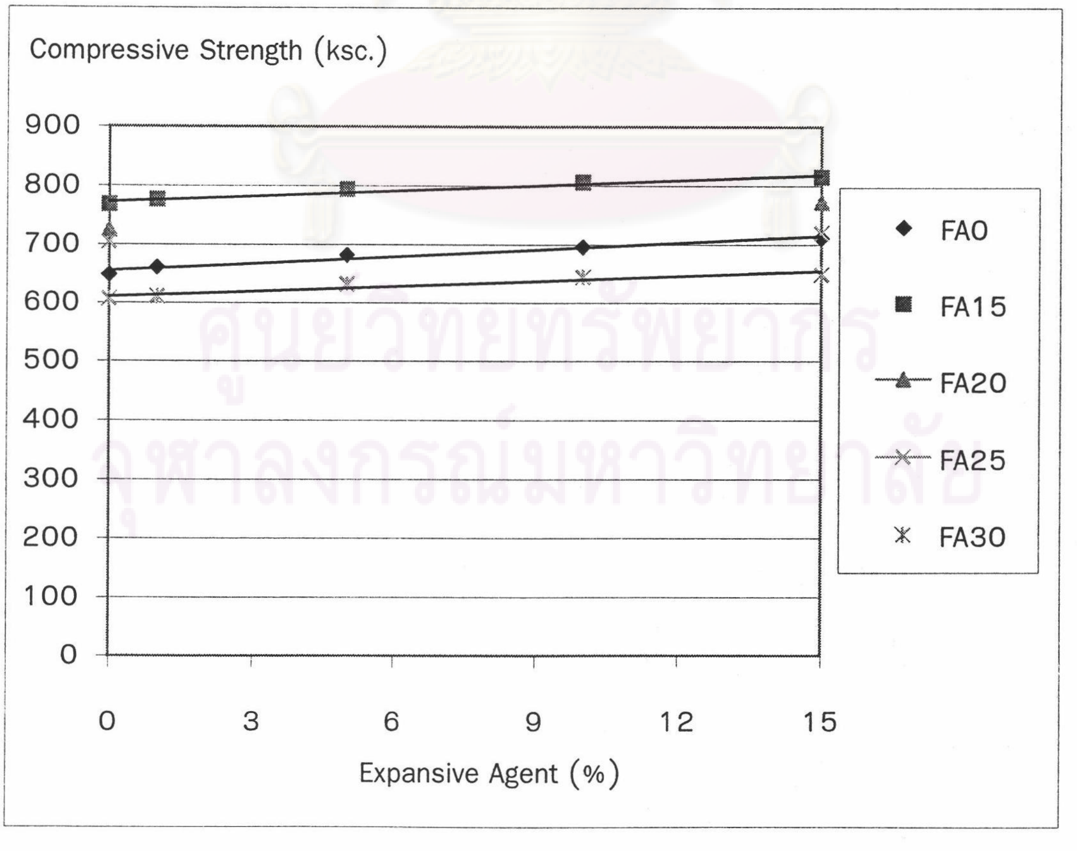

Fig. 5.22 Compressive strength of concrete by expansive agent

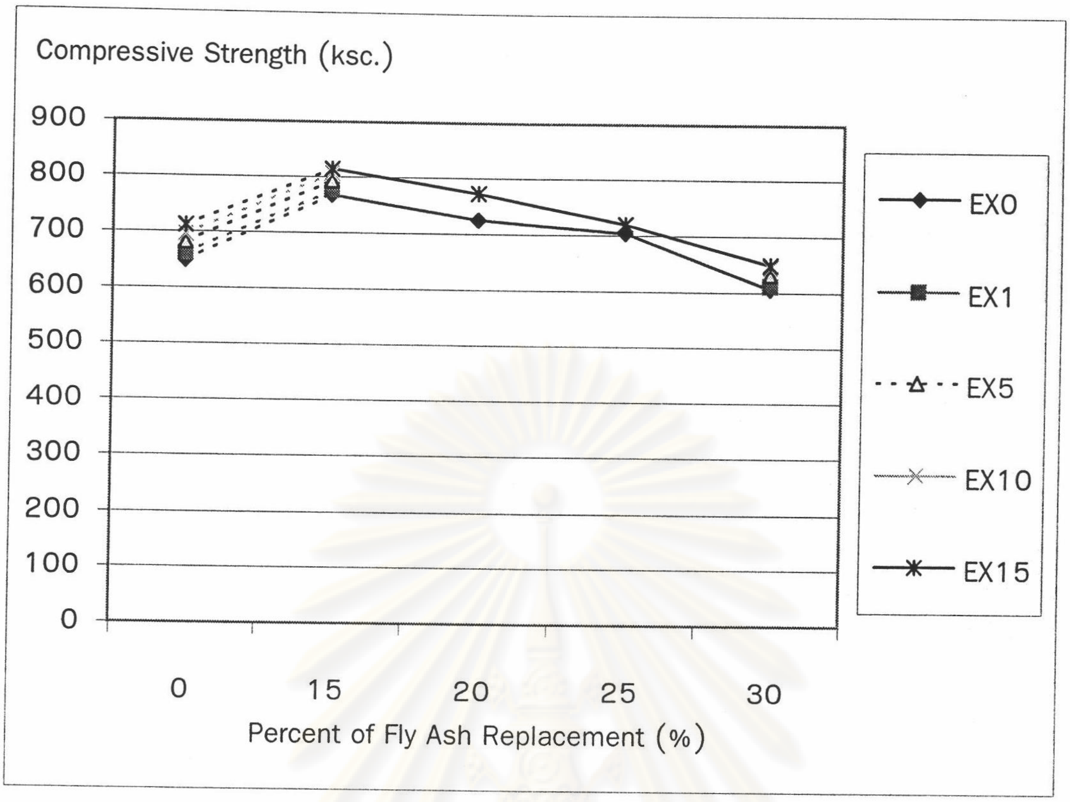

Fig. 5.23 Compressive strength of concrete by fly ash replacement

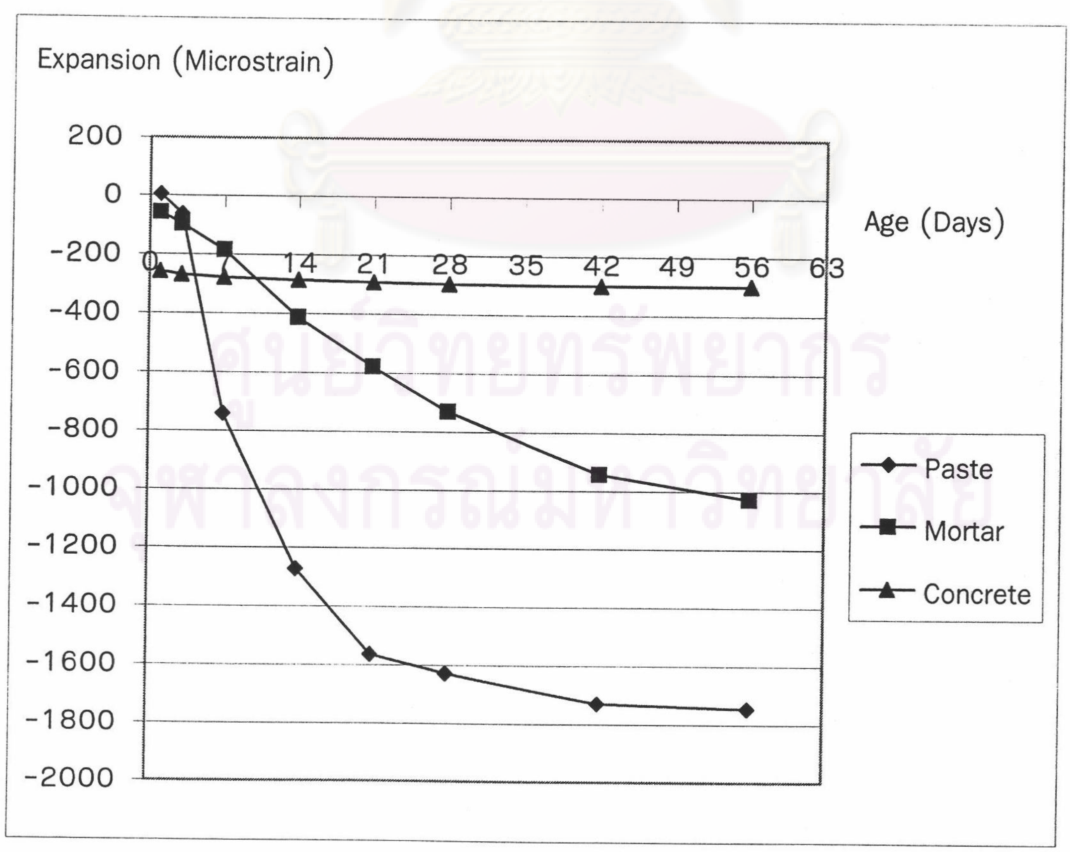

Fig. 5.24 Shrinkage of cement paste, mortar and concrete

Fig. 5.25 Mixture of concrete

Fig. 5.26 Admixture “Daracem 100”

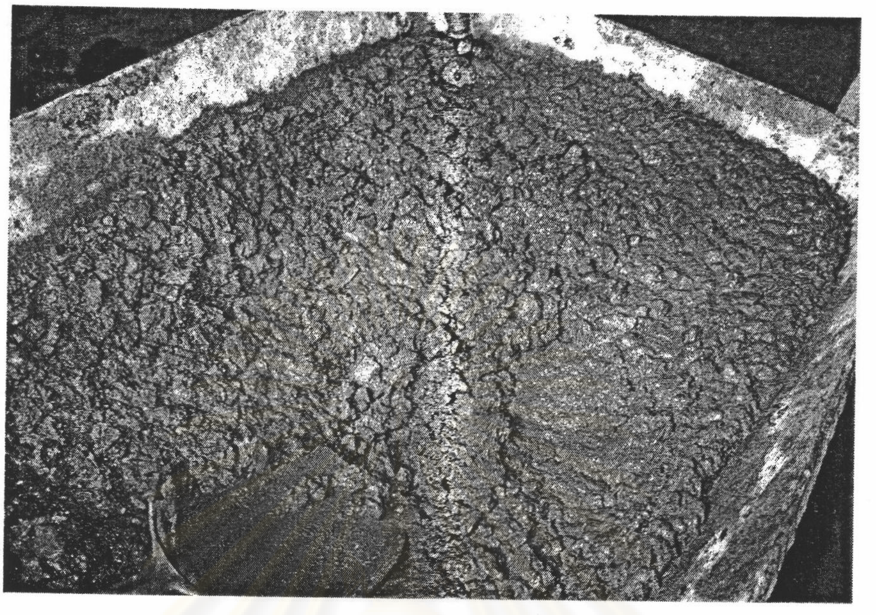

Fig. 5.27 Fresh concrete

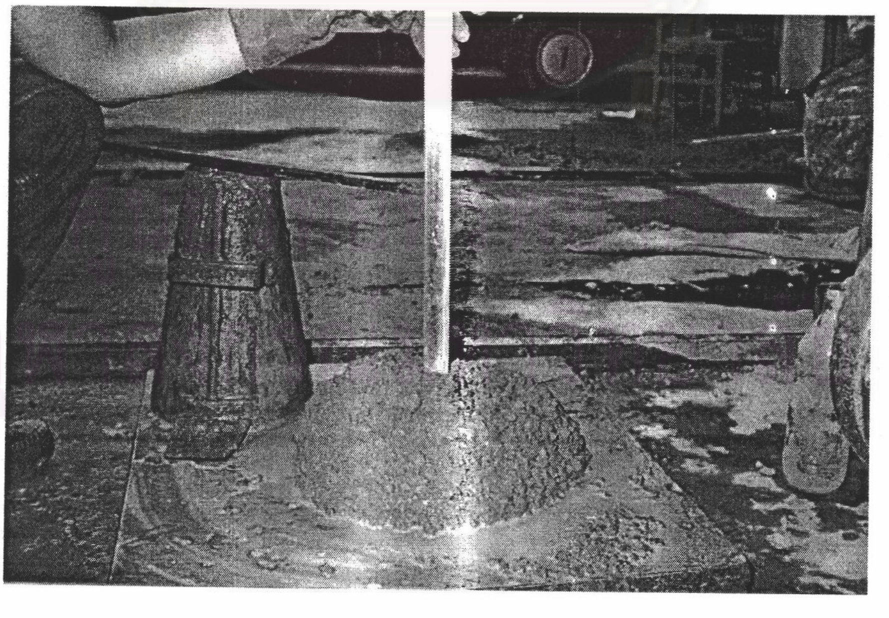

Fig. 5.28 Slump of shrinkage compensating concrete

Fig. 5.29 Flow of shrinkage compensating concrete

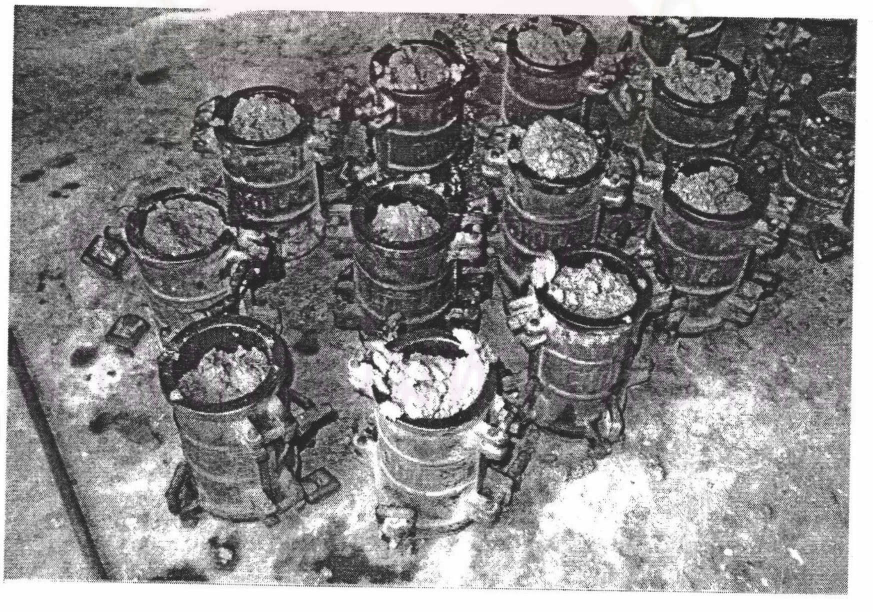

Fig. 5.30 Preparation of cylinder specimen

Fig. 5.31 Preparation of cylinder specimen

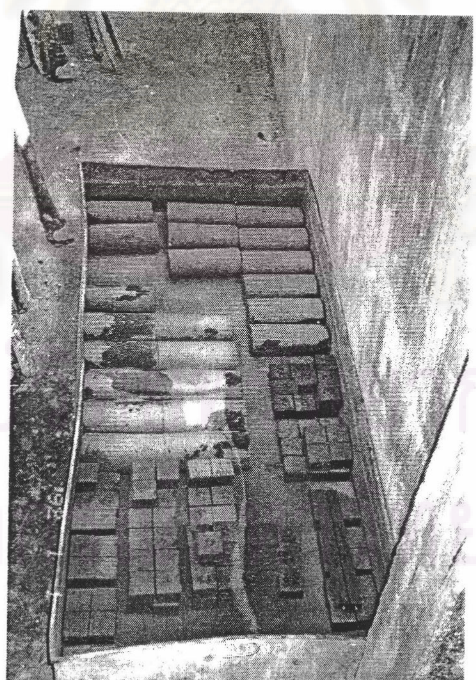

FIG. 5.32 Curing

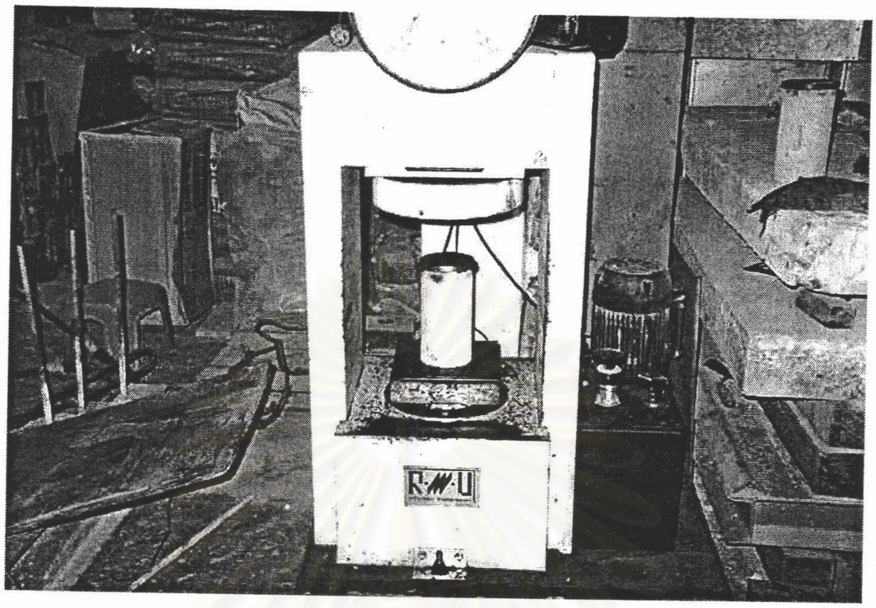

Fig. 5.33 Compressive strength test