CHAPTER 3

EXPERIMENTAL INVESTIGATION

The experiments, which satisfy the simulation of the autogenous shrinkage model, are separated into two parts. The first one is free shrinkage of paste, and the other one is shrinkage of no-fine concrete, mortar, and concrete. Many experiments tested by Deesawangnade (1994) were conducted on no-fine concrete, mortar, and concrete in order to satisfy the aggregate stiffness model. However, the additional tests of no-fine concrete with different maximum size of coarse aggregate from previous study and free shrinkage of paste to simulate the model are conducted in this study.

3.1 Materials

3.1.1 Cement

Ordinary portland cement type 1 (Elephant brand) and high early strength portland cement type 3 manufactured by the Siam Cement Co.,Ltd. Thailand, and sulfate resistance portland cement type 5 manufactured by TPI Polene Co.,Ltd. are used throughout the study. All 50 kg./bag of cement were each encased in an additional plastic bags, and stored in a dry place. The chemical composition and physical properties were analyzed. The cement characteristics are shown in Table A.1 and Table A.2.

3.1.2 Fly ash

In this experiment, fly ash was collected from Mae-Moh electric power plant of Electricity Generating Authority of Thailand in Lampang province. Fly ash was kept in sealed plastic bags in order to prevent contamination from moisture in the air. Fly ash in this experiment was designated as FM2, while the data obtained by previous research were designated as FM1 and FT. Different kinds of fly ash are used for the purpose of model calibration and verification as well. From the scope of the study, we know that the CaO, SiO_2, and SO_3 content of fly ash affect autogenous shrinkage. Then the fly ash used in this study will be different in the CaO, SiO_2, and SO_3 content. Chemical composition and physical properties of fly ash are shown in Table A.3 and Table A.4.

3.1.3 Coarse aggregate

The maximum size of crushed limestone coarse aggregate is 8 mm. The bulk specific gravity based on saturated surface dry basis determined in accordance with ASTM C127-88 was 2.73. The sieve analysis result of coarse aggregate is given in Table 3.1.

Table 3.1 Sieve analysis of coarse aggregate

Sieve No.	Sieve Opening	Percent Retained (%)
1″	25.00	–
3/4″	19.00	–
1/2″	12.50	–
3/8″	9.38	–
1/4″	6.25	42.51
Pan	–	57.49
Total		100

3.1.4 Water

Ordinary tap water, supplied by the civil engineering laboratory of Sirindhorn International Institute of Technology, Thammasat University, was used for all mixes.

3.1.5 Aluminum foil

Aluminum foil was used to wrap the specimen after demolding immediately in order to prevent both permeation of moisture from outside and evaporation of moisture into the outer environment.

3.2 Mix Proportions and Specimen Preparation

The experimental program was designed to ascertain the volume change of the specimens due to the autogenous shrinkage. Then, paste specimens were prepared with ordinary portland cement type 1, high early strength portland cement type 3, sulfate resistance portland cement type 5 and fly ash. The percentages of water to cement ratio were controlled at 0.25, 0.30, and 0.40 for type 1 cement, and constant at water to cement ratio at 0.30 for type 3 and type 5 cement. Three percentages of the replacement by weight of fly ash at 0%, 30%, and 50% were applied to see the effect on autogenous shrinkage.

Paste was selected instead of mortar or concrete specimen because autogenous shrinkage occurs only in cementitious matrix. For autogenous shrinkage of concrete, the concept of 2-phase model was proposed. Specimen having dimension of 25×25× 285 mm. for linear strain measurement. At final setting time, all specimens were demolded and sealed with aluminum foil in order to prevent both permeation and evaporation of moisture.

One mix of no-fine concrete was conducted with water to cement ratio of 0.30 and coarse aggregate volume concentration to volume concentration of the densely compacted coarse aggregate ratio of 0.40.

3.3 Curing Condition

Paste specimens were demolded at 3 hours after mixing. After that, the specimens under sealed condition were wrapped with aluminum foil immediately. The sealed specimens were stored at 25±2°C with a relative humidity of 80±5 %. The specimens under submerged condition were immersed in water after demolding. The study of effect of temperature was conducted on 25°C and 40°C.

3.4 Linear Strain Measurement

Measurement of linear strain conformed to the ASTM 596-89 for examination of linear strain of specimens subjecting to expansion and shrinkage. In this experiment, digital strain gauge was used to measure the strain as shown in Fig. 3.1. The zero age of specimens indicating the starting of autogenous shrinkage was measured at 3 hours after mixing. Four specimens are prepared for each mix to have the average linear strain. Strain measurements were taken frequently for the first 2 weeks after demolding, and then the frequency of the readings were gradually reduced as the shrinkage rate stabilized with time. The autogenous shrinkage measurement was conducted for 60 days.

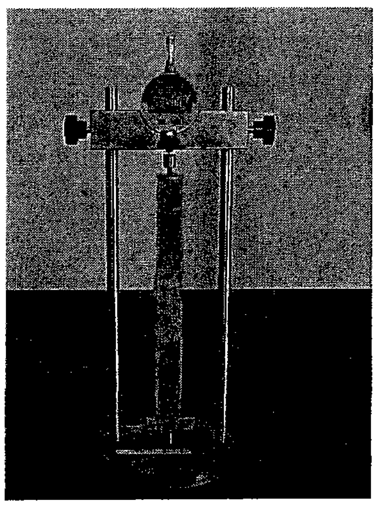

Fig. 3.1 Digital strain gauge

3.5 Experimental Program

Many researchers studied the cause of autogenous shrinkage, its mechanism, various influencing factors and how to reduce the magnitude of autogenous shrinkage. The results of investigations from the other researchers were adopted in this study. There are additional tests on the effect of chemical and physical properties of cement on autogenous shrinkage from ordinary portland cement type 1, high early strength portland cement type 3, sulfate resistance portland cement type 5, and ordinary portland cement type 1 containing one type of fly ash (FM2) were investigated.

3.5.1 Influence of chemical composition of cement

The objective is to investigate the effects of chemical composition of cement on the autogenous shrinkage. Ordinary portland cement type 1, high early strength portland cement type 3, and sulfate resistance portland cement type 5 at constant water to cement ratio equals to 0.30 were tested for verification of the model.

3.5.2 Influence of fineness of cement

This part deals with the effect of fineness of cement on autogenous shrinkage. Each type of cement has different fineness. Then the effect of fineness of type 1 cement (3190 cm^2/g), type 3 cement (4770 cm^2/g), and type 5 cement (3760 cm^2/g) is determined. The test program was designed by using 3 types of cement with constant water to cement ratio of 0.30. There are additional 2 data of autogenous shrinkage of pastes made from Japanese type 1 cement with Blaine fineness 5570 and 7430 cm^2/g.

3.5.3 Influence of water to binder ratio

As known that the effective parameter on hydration reaction of cement is water to binder ratio, then it influences the magnitude of autogenous shrinkage. For the test program, the tested mix proportions were conducted on pastes made from type 1 cement, and type 1 cement with fly ash FM1, FM2, and FT at water to binder ratio of 0.25, 0.30, and 0.40.

3.5.4 Influence of types of fly ash

There are previous studies on the effect of types of fly ash on autogenous shrinkage (Sudsangiam 1993 and Chanmeka 1999). So additional test was conducted on type 1 cement with one type of fly ash (FM2) at water to binder ratio of 0.25, 0.30, and 0.40. The paste specimens tested by Chanmeka have the dimension of 25×25×285 mm., while the paste specimens tested by Sudsangiam have the dimension of 40× 160×15 mm. Both experiments were cured in the constant temperature and humidity room (25±2°C and R.H. = 60±5%).

3.5.5 Influence of replacement percentage of fly ash

In order to investigate the effect of fly ash content on autogenous shrinkage of cement paste, the replacement percentages by weight were controlled at 0%, 30%, and 50% for type 1 cement. The water to binder ratio were controlled at 0.25, 0.30 and 0.40.

3.5.6 Influence of curing temperature

Effect of curing temperature on autogenous shrinkage are studied on sealed specimens of cement paste at water to binder ratio of 0.30 and 0.40 with the curing temperature of 25°C and 40°C.

3.5.7 Expansion of submerged cement paste

The objective is to investigate the water swelling and effects of fly ash on the expansion of cement paste submerged in water. The experiment was controlled by using type 1 cement. The water to binder ratio are 0.25, 0.30, and 0.40. The replacement percentages of fly ash are 0%, 30%, and 50%.

3.6 Mix Proportion

Mix proportions of tested cement pastes of autogenous shrinkage are shown in Table 3.2. The test program was separated into 2 curing conditions, which are sealed condition and submerged condition. Various types of cement and fly ash, water to binder ratio, and replacement of fly ash are specified. The chemical composition and physical properties of cement and fly ash are shown in Appendix A. Mix proportion of tested no-fine concrete is shown in Table 3.3.

Table 3.2 Mix proportions of the tested cement pastes

Mix No.	Designation	$\frac{w}{c+f}$	$\frac{f}{c+f}$	Cement (kg/m^3)	Fly Ash (kg/m^3)	Curing Condition
1	C1-25-02	25	–	1762	–	Sealed
2	C1-30-02	30	–	1620	–	Sealed
3	C1-40-02	40	–	1394	–	Sealed
4	C3-30-02	30	–	1394	–	Sealed
5	C5-30-02	30	–	1394	–	Sealed
6	C1-FM1-25-32	25	30	1130	484	Sealed
7	C1-FM1-25-52	25	50	765	765	Sealed
8	C1-FM1-30-31	30	30	1046	448	Submerged
9	C1-FM1-30-32	30	30	1046	448	Sealed
10	C1-FM1-30-52	30	50	710	710	Sealed
11	C1-FM1-40-32	40	30	910	390	Sealed
12	C1-FM1-40-52	40	50	622	622	Sealed
13	C1-FM2-25-31	25	30	1130	484	Submerged
14	C1-FM2-25-32	25	30	1130	484	Sealed
15	C1-FM2-25-51	25	50	765	765	Submerged
16	C1-FM2-25-52	25	50	765	765	Sealed
17	C1-FM2-30-31	30	30	1046	448	Submerged
18	C1-FM2-30-32	30	30	1046	448	Sealed
19	C1-FM2-30-51	30	50	710	710	Submerged
20	C1-FM2-30-52	30	50	710	710	Sealed
21	C1-FM2-40-31	40	30	910	390	Submerged
22	C1-FM2-40-32	40	30	910	390	Sealed
23	C1-FM2-40-51	40	50	622	622	Submerged
24	C1-FM2-40-52	40	50	622	622	Sealed
25	C1-FT-25-32	25	30	1130	484	Sealed
26	C1-FT-25-52	25	50	765	765	Sealed
27	C1-FT-30-31	30	30	1046	448	Submerged

Mix No.	Designation	$\frac{w}{c+f}$	$\frac{f}{c+f}$	Cement (kg/m³)	Fly Ash (kg/m³)	Curing Condition
28	C1-FT-30-32	30	30	1046	448	Sealed
29	C1-FT-30-52	30	50	710	710	Sealed
30	C1-FT-40-32	40	30	910	390	Sealed
31	C1-FT-40-52	40	50	622	622	Sealed

Table 3.3 Mix proportions of the tested no-fine concrete

Mix No.	Designation	W/C (%)	Cement (kg/m³)	Coarse (kg/m³)	$\frac{n_g}{n_{g,max}}$	n_g
1	G30-40	30	1233	624	0.40	0.2287

n_g = coarse aggregate volume concentration

$n_{g,max}$ = aggregate volume concentration of the densely compacted coarse aggregate in cubic meter of bulk volume