CHAPTER 4

TEST RESULTS AND DISCUSSION

4.1 General

During hydration, a very fine porosity develops within the hydrated cement paste. The fine porosity drains water from the coarser capillary network in which menisci are developed. The menisci appearing in the capillary system create tensile stresses within the cement paste, which shrinks under these stresses. At a macroscopic level, it is observed that some water is leaving the coarser capillaries as if the concrete is drying, but this water depletion in the capillary system is not accompanied by a loss in mass. This drying phenomenon is called self-desiccation and the resulting shrinkage is called autogenous shrinkage.

The practical procedures to avoid autogenous shrinkage do not yet exist, but several options are already available to improve the present situation (Aitcin 1999).

- The saturated lightweight aggregates can be used as a source of internal water to overcome autogenous shrinkage.

- The shrinkage-reducing admixtures decrease the tensile stresses developed at the surface of the menisci in the capillaries when concrete subjected to self-desiccation.

- The appropriate water curing as external source of water that starts before the full development of hydration reactions is the effective way to compensate the depletion of water.

- The replacement of some part of cement with fly ash is effective for reducing autogenous shrinkage. Expansion compensates shrinkage by the effect of SO_3 content in fly ash.

Although there already exist several alternatives to overcome the volumetric changes of concrete, but in any case, it is necessary to be aware of the importance of such a phenomena from a durability point of view and to invest money in concrete curing. One of the effective ways to apply for reducing autogenous shrinkage purpose is the replacement of some part of cement with fly ash.

Many researchers studied mechanism and how to improve autogenous shrinkage. Then, many test results were obtained. In this study, the previous data from Tazawa and Miyazawa (1996), Sudsangium (1993), and Chanmeka (1999) were obtained to verify the model. The additional tests of several types of cement and one type of fly ash were conducted by the author.

4.2 Effect of Chemical Composition of Cement

The investigation of the effect of chemical composition of cement, especially for C_3A, C_4AF, C_3S, and C_2S was conducted on paste made from type 1, type 3, and type 5 portland cement. The percentage of water to binder ratio was controlled at 0.30 for all types of cement. Specimens having dimension of 25×25×285 mm were used for linear measurement. The measurement was started at 3 hours after mixing. After demolding, the specimens were sealed with aluminum foil and kept in the constant temperature at 25°C with a relative humidity of 80±5%.

Fig. 4.1 illustrates the results of chemical composition of cement on autogenous shrinkage. The cement characteristics are shown in Table A.1-A.2. It can be seen that the chemical properties of type 1 cement are similar to type 3 cement. Then, the effect of chemical composition of cement was explained clearly by the difference of type 1 cement and type 5 cement. Ordinary portland cement type 1 shows early development of autogenous shrinkage and has the highest strain in long term, whereas sulfate resistance portland cement type 5 has a lower autogenous. This result can be explained that C_3A and C_3S have greater influence than C_2S and C_4AF because it reacts rapidly at the early age of cement paste, also making the hydrated structure denser too.

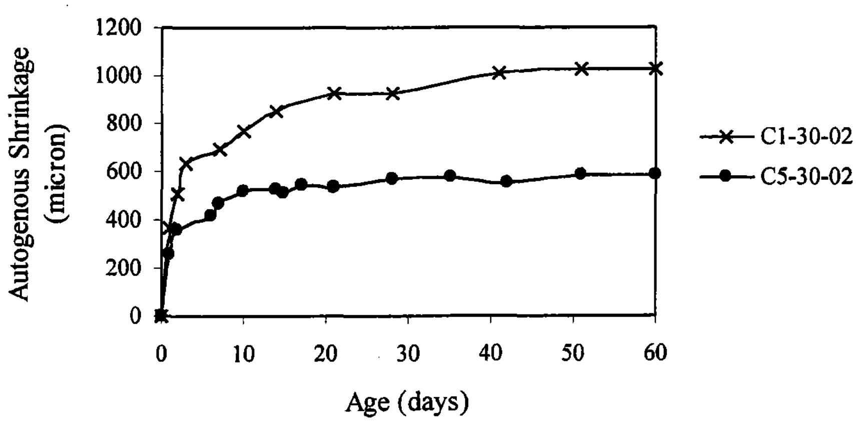

Fig. 4.1 A comparison of autogenous shrinkage of type 1 and type 5 cement paste with water to cement ratio 0.30 at 25°C, 80% R.H.

4.3 Effect of Fineness of Cement

In the cement production, the fineness of different batch may be different, but not much. However for different kinds of cement, there will be great difference such as type 3 cement has a greater fineness than type 1 cement. In order to study the effect of fineness of cement, the test results of type 1 cement and type 3 cement which has a similar chemical composition but different in fineness were considered. Also, Japanese type 1 cement from Tazawa and Miyazawa (1993) with different Blaine fineness as 5570 cm^2/g., and 7430 cm^2/g were used. The percentage of water to cement ratio was controlled at 0.30 for all.

explained that the high fineness influences the hydration process by accelerating the hydration process, and early shrinkage will be increased. Then, cement with fineness 7430 cm^2/g gives the highest strain due to autogenous shrinkage. High fineness also makes capillary pores finer than low fineness. Then, cement with fineness 7430 cm^2/g gives the highest strain due to autogenous shrinkage.

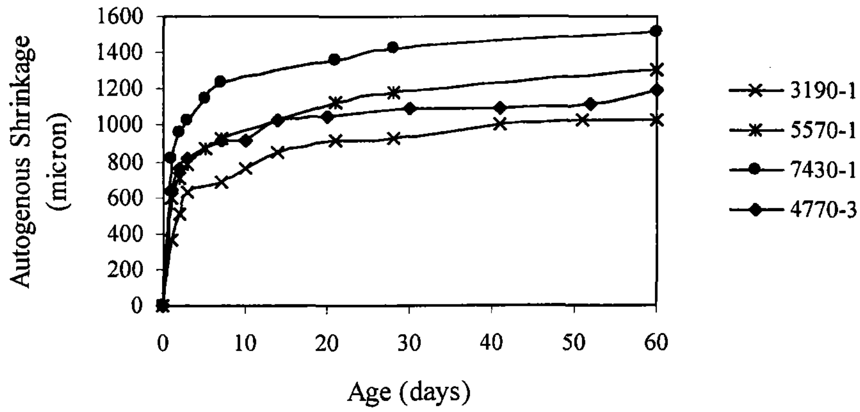

Fig. 4.2 A comparison of autogenous shrinkage of type 1 cement paste with fineness of cement of 3190, 5570, and 7430 cm^2/g and type 3 cement paste with fineness of cement of 4770 cm^2/g at water to cement ratio 0.30 at 25°C, 80% R.H.

4.4 Effect of Water to Binder Ratio

To investigate the effect of water to binder ratio, autogenous shrinkage of pastes with water to binder ratio equal to 0.25, 0.30, and 0.40 were observed. In this case the experiment was conducted on the type 1 cement with and without fly ash. The replacement percentages of fly ash are 0%, 30% and 50% using FM1, FM2 and FT types of fly ash. In all mixes, the rate of shrinkage is high at the early ages, particularly during the first week. Subsequently, it becomes lower and almost diminishes after 4 weeks. These characteristics are similar to those of hydration of cementitious material and support the hypothesis that autogenous shrinkage is the result of hydration.

The obtained data of autogenous shrinkage of cement paste with and without fly ash are shown in Fig. 4.3 to Fig. 4.9. The results reveal that the magnitude of autogenous shrinkage increases with decreasing of water to binder ratio. The explanation for that is the small amount of water used for mixing causes less and smaller capillary voids leading to the increasing of capillary tension and autogenous shrinkage.

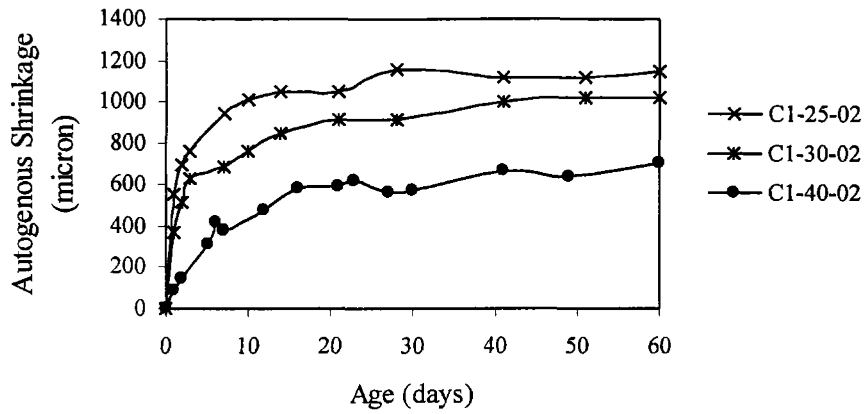

Fig. 4.3 A comparison of autogenous shrinkage of type 1 cement paste with water to cement ratio of 0.25, 0.30, and 0.40 at 25°C, 80% R.H.

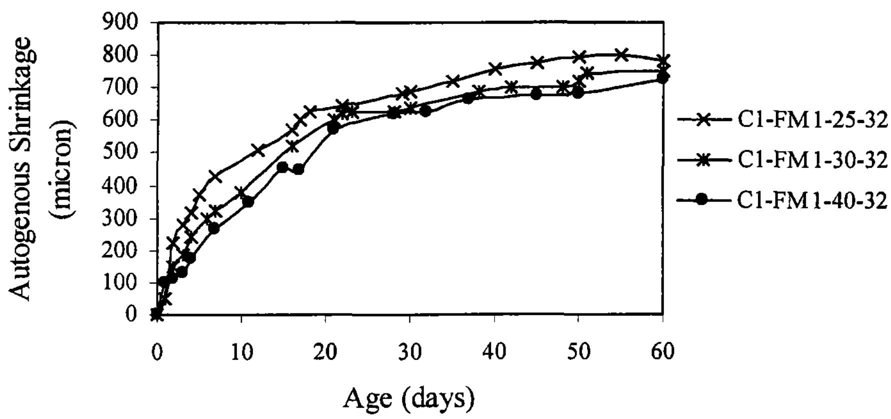

Fig. 4.4 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FM1 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

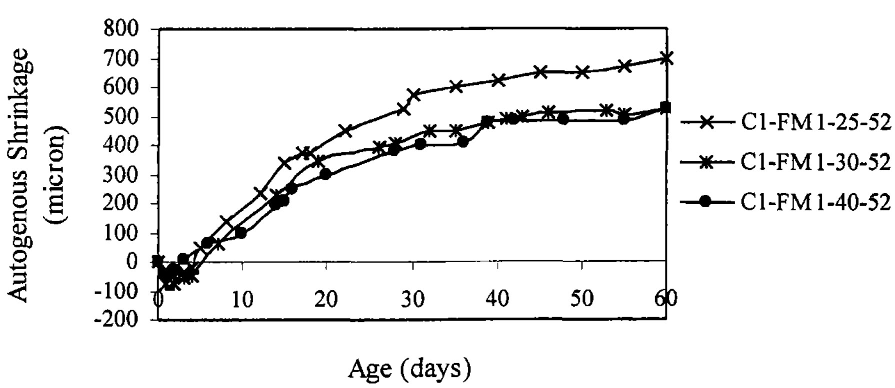

Fig. 4.5 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FM1 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

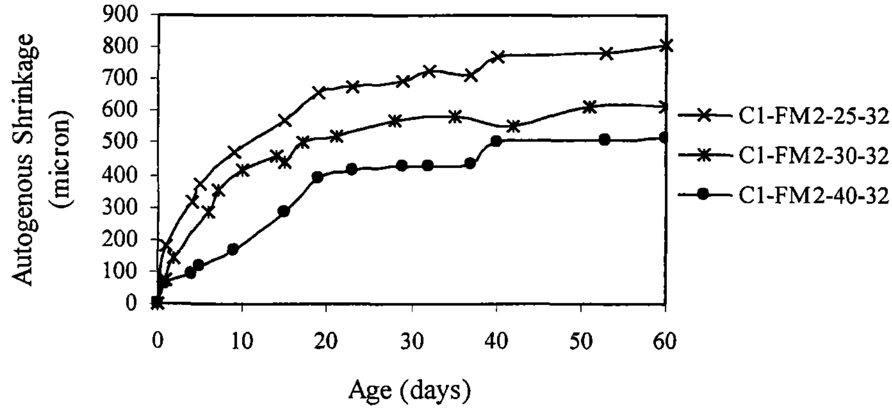

Fig. 4.6 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FM2 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 80% R.H.

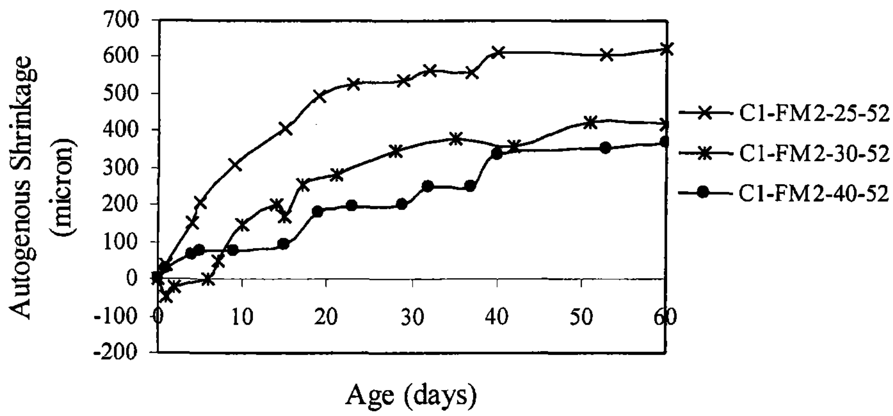

Fig. 4.7 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FM2 with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 80% R.H.

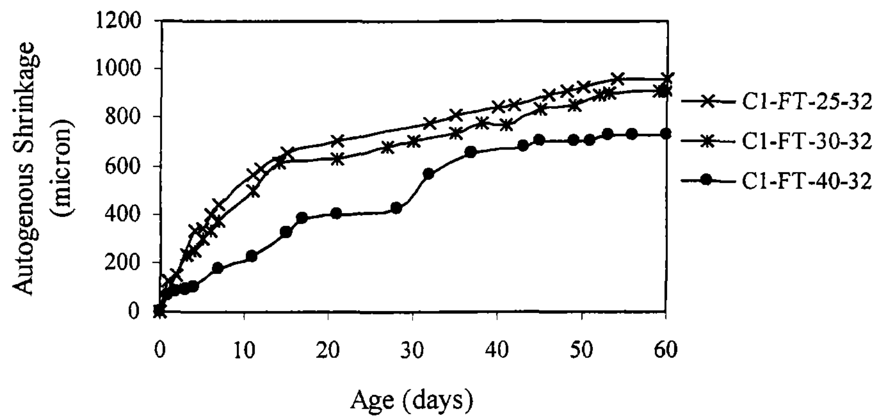

Fig. 4.8 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FT with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

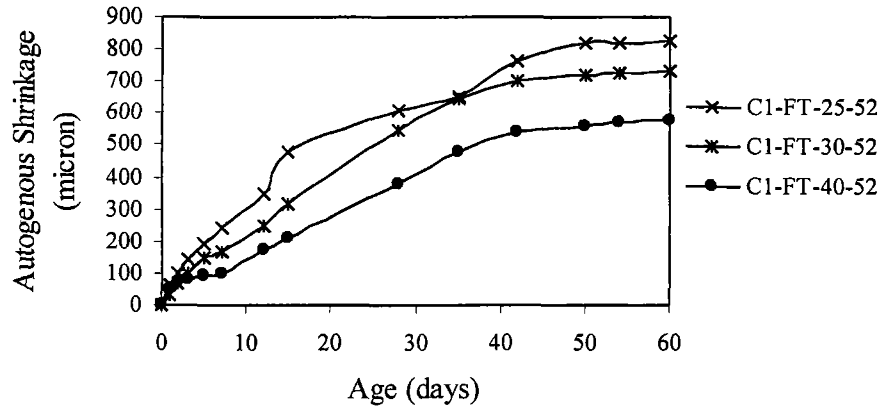

Fig. 4.9 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FT with water to binder ratio of 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

4.5 Effect of Chemical Composition of Fly Ash

Fly ash is one of the pozzolans confirmed to be effective for improving various properties of concrete. One of the improvement is autogenous shrinkage. Due to inconsistency of the chemical and physical properties of fly ashes, an attempt has been made to study the properties of concrete utilizing fly ashes. This part summarizes the test results obtained from Chanmeka (1999) (FM1 and FT) and from the author (FM2) on autogenous shrinkage of pastes mixed with various types of fly ash with different chemical composition. The chemical compositions of fly ash are shown in Table A.3.

Fig. 4.10 and Fig. 4.11 show the comparison of strain of paste specimens containing 30% and 50% fly ash, respectively, with that of cement. It is shown that all specimens with fly ash exhibit smaller autogenous shrinkage than the cement paste.

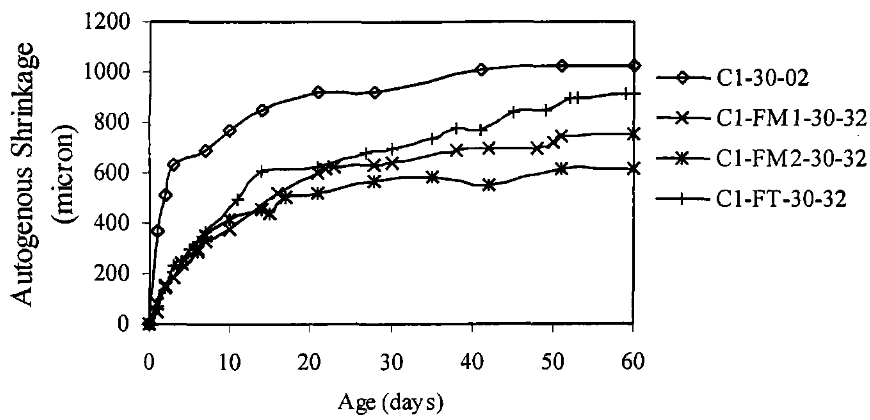

Fig. 4.10 A comparison of autogenous shrinkage of type 1 cement paste having 30% replacement of FM1, FM2, and FT with water to binder ratio of 0.30

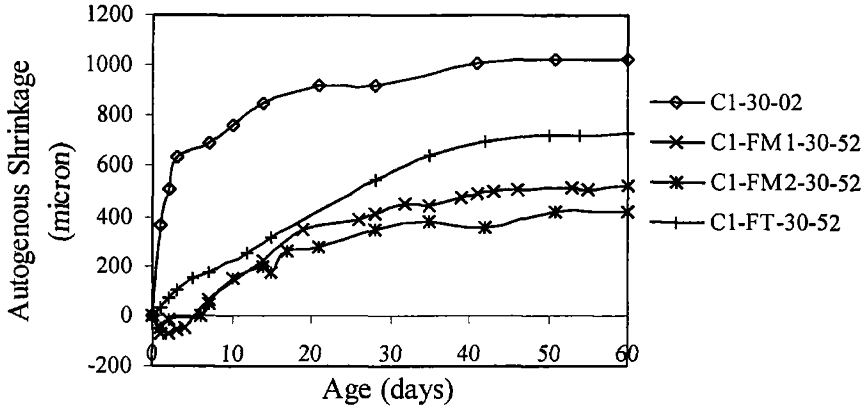

Fig. 4.11 A comparison of autogenous shrinkage of type 1 cement paste having 50% replacement of FM1, FM2, and FT with water to binder ratio of 0.30

From the test results, the effect of chemical composition of fly ash on autogenous shrinkage was found to be uncertain depending on the test condition. In this case, FM1 and FT were tested at a relative humidity of 60±5%, while FM2 were test at a relative humidity of 80±5%. However, the test results obtained from the same test condition indicated similar trend that fly ash which contains high SO_3 content would reduce autogenous shrinkage.

For FM1, FM2, and FT, it can be concluded that cement paste with FT that has very low SO_3 content (0.15%) has a higher autogenous shrinkage than cement paste with FM1 (1.58%) and FM2 (1.04%). It is obvious by comparing results of pastes containing FM1, FM2, and FT that the higher the SO_3 content of the fly ash, the larger the autogenous shrinkage reduction. The reason of that is SO_3 reacts with $Ca(OH)_2$ and water during hydration, and form additional gypsum and also yields ettringite that is generally recognized to be the cause of the chemical expansion in fly ash cement paste. As a result, autogenous shrinkage in fly ash cement paste is compensated by the chemical expansion.

4.6 Effect of Fly Ash Content

From the results shown in Fig. 4.10 to Fig. 4.11, it can be concluded that increasing percentage of fly ash causes decreasing magnitude of autogenous shrinkage for all types of fly ash. This can be explained based on three mechanisms of autogenous shrinkage reduction. The first, which occurs in all types of fly ash, was the result of particle shape of fly ash. Fly ash particles were spherical, therefore they retained less water than cement particles which were irregular. This resulted in a larger free water content in the mixture with fly ash than in the mixture without fly ash when prepared with the same w/c. As autogenous shrinkage is the result of water consumption in the hydration process, larger free water content can, therefore, reduce the shrinkage. The second, which is the special characteristics of high SO_3 fly ash, is the chemical expansion which compensates the autogenous shrinkage. The third, pozzolanic reaction due to fly ash reacts slowly, then when some part of cement was replaced with fly ash, the reaction will be retarded. Although, the pozzolanic reaction will occur in long term, but the cement paste already get hardened with higher stiffness against the shrinkage, so the shrinkage will be small. These mechanisms will be much effective when the replacement of fly ash is larger.

4.7 Effect of Curing Temperature

The large increase in heat evolution during the early stages of hydration produced by increase in temperature. The relative rates of hydration at different temperatures are inversely related to the time required at each temperature to reach the equivalent degree of hydration. The samples cured at a higher temperature had lower porosity at early age. This is reasonable because degree of hydration for samples cured at the higher temperature is larger than for those cured at a lower temperature, and the porosity decreases with increased degree of hydration. In other word, the lower curing temperature retards the hydration process. However the degree of hydration for samples cured at higher temperatures will eventually be smaller than cured at lower temperature after longer times. Also the samples cured at high temperature develops more coarse pore structure. Autogenous shrinkage is from the surface tension of capillary pores, and smaller pores create a higher stress. As a result, the samples cured at a higher curing temperature with a lower porosity at early age develop a larger autogenous shrinkage initially. However, it will be gradually increase at later age, and then it will be lower than the samples cured at a lower temperature. The test results to compare the autogenous shrinkage of samples cured at temperature of 25°C and 40°C with water to cement ratio at 0.30 and 0.40 are shown in Fig. 4.12.

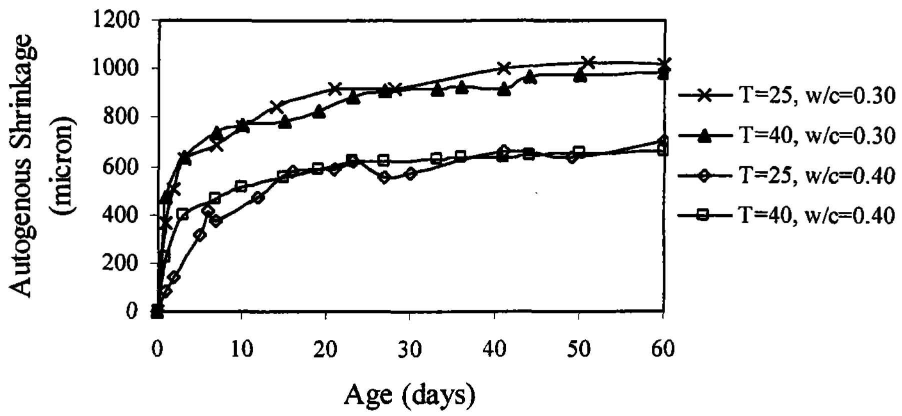

Fig. 4.12 A comparison of autogenous shrinkage of type 1 cement paste cured at temperature of 25°C and 40°C with water to cement ratio of 0.30 and 0.40

4.8 Expansion

Expansion can be considered to consist of two components, namely, swelling due to water absorption and chemical expansion. The submerged curing condition was designed for the study of expansion because it was found that the chemical expansion requires water. Since autogenous shrinkage was observed under sealed condition, then the expansion of swelling due to water absorption did not exist.

From the test results, it can be seen that the magnitudes of expansion of FT having 30% and 50% replacement are not so different. This indicated that the expansion is not caused by gypsum and ettringite formation or in other words, the expansion is caused only by swelling in cement-fly ash pastes due to water absorption. Then, the results of chemical expansion of pastes were obtain by subtracting the total expansion of the pastes containing FM1 and FM2 with the expansion of pastes containing FT, which was assumed to have only water swelling.

4.9 Effect of Aggregate Content

Aggregate phase consisting of coarse and fine aggregates is considered much more stable in volume. Aggregate particles contacts have an effect to restrain shrinkage of paste phase. Then, autogenous shrinkage depends on amount of aggregates or volume concentration of aggregates. High volume concentration of aggregates reduces more shrinkage in cement paste than low volume concentration of aggregates. The experimental results of aggregates effect was adopted from Deesawangnade (1994). The specimens to determine linear strain measurement have dimensions of 40×160×15 mm. for mortar and cement paste. The specimens having dimension of 40×40×160 mm. were applied to no-fine concrete and binary mixture. Fig. 4.13, Fig. 4.14, Fig. 4.15, and Fig. 4.16 show the relationship between autogenous shrinkage and age of specimens by varying volume concentration of fine aggregate, coarse aggregate, and binary mixture of fine and coarse aggregates, respectively. The details of mix proportions are illustrated in Table B.1.

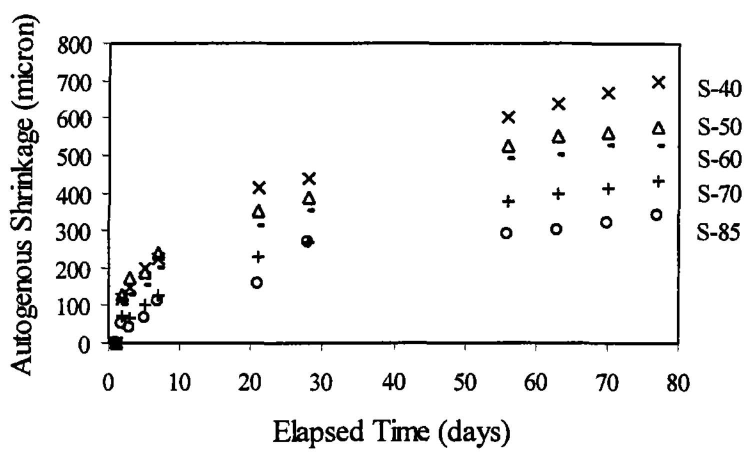

Fig. 4.13 A comparison of autogenous shrinkage of mortars at different volume concentration ratio of fine aggregate ($n_s/n_{s,max}$) with water to cement ratio of 0.30

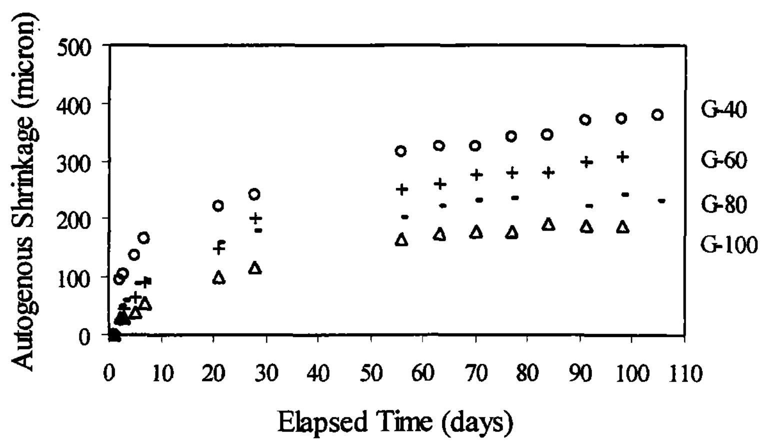

Fig. 4.14 A comparison of autogenous shrinkage of no-fine concrete at different volume concentration ratio of coarse aggregate ($n_g/n_{g,max}$) with water to cement ratio of 0.30

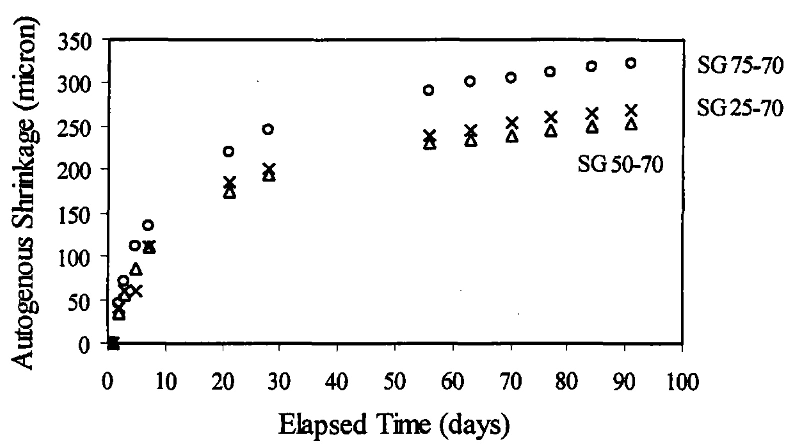

Fig. 4.15 A comparison of autogenous shrinkage of concrete at different sand to total aggregates ratio with volume concentration ratio of binary mixture ($n_a/n_{a,max}$) of 0.70 and water to cement ratio of 0.30

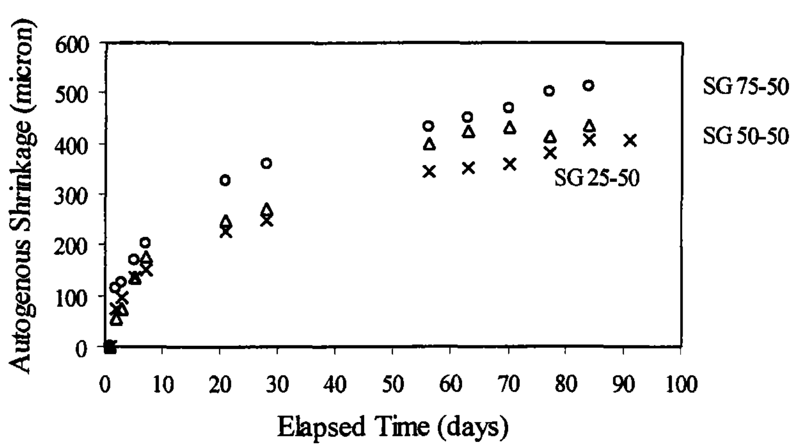

Fig. 4.16 A comparison of autogenous shrinkage of concrete at different sand to total aggregates ratio with volume concentration ratio of binary mixture ($n_a/n_{a,max}$) of 0.50 and water to cement ratio of 0.30

4.10 Effect of Maximum Size of Coarse Aggregate

Crushed limestone coarse aggregate was classified based on maximum size of aggregate (G_{max}) in order to find the effect of maximum size of aggregate on autogenous shrinkage. Large maximum size of coarse aggregate reduces shrinkage in concrete than aggregate with small maximum size as can be seen by the comparison between no-fine concrete with maximum size of 20 mm. tested by Deesawangnade (1994) and maximum size of 8 mm. tested by the author in Fig. 4.17. The volume concentration ratio of coarse aggregate was controlled at 0.40. The experimental results showing effect of maximum size of coarse aggregate are shown in Fig. 4.17.

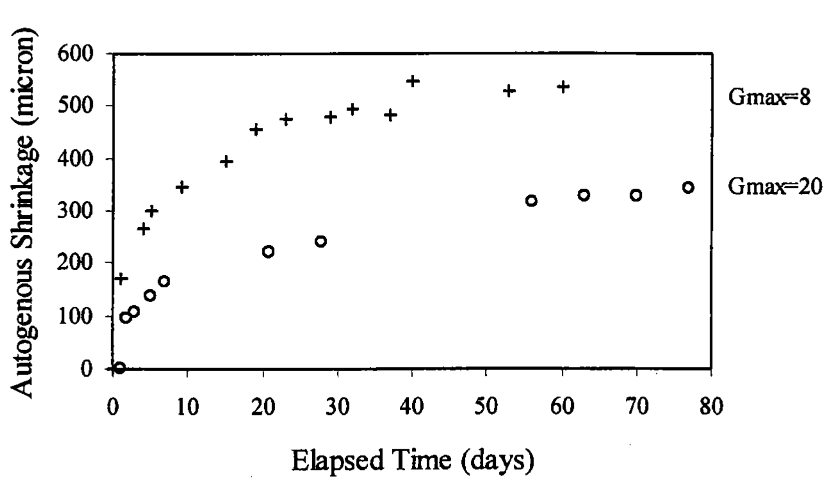

Fig. 4.17 A comparison of autogenous shrinkage of no-fine concrete at different maximum size (G_{max}) of coarse aggregate with water to cement ratio of 0.30