CHAPTER 9

VERIFICATION

9.1 Verification of Aggregate Stiffness

The verification of aggregate stiffness of coarse aggregate, fine aggregate, and binary mixture between coarse and fine aggregates is presented in form of comparison between experimental data and computed results from the model.

9.1.1 Stiffness of coarse aggregate

The tests were performed on no-fine concrete specimens with the volume concentration ratio of coarse aggregate ($n_g/n_{g,max}$) equal to 1.0, 0.80, 0.60, 0.40, which are equivalent to the volume concentration of coarse aggregate (n_g) equal to 0.55, 0.44, 0.33, 0.22, respectively. Mixes were made with the water to cement ratio of 0.30 and under sealed condition. Maximum size of coarse aggregate was controlled at 20 mm. There was additional test by author for no-fine concrete with maximum size of coarse aggregate of 8 mm.

It may be mentioned that the stiffness of aggregate phase is difficult to find by a direct test, so the stiffness of aggregate phase is essential to be obtained by application of indirect method. The effect of coarse aggregate stiffness, which restrains shrinkage of concrete, is proposed based on two-phase model for shrinkage of concrete in Eq. (5.12). In the two-phase model, paste stiffness (E_p) was obtained by the model in Chapter 7 and free shrinkage of paste in concrete (ε_{po}) as well as shrinkage of concrete (ε_{conc}) came from experimental results tested by Deesawangnade (1994). Consequently, the relation between the stiffness of coarse aggregate (E_a) and the shrinkage of concrete (ε_{conc}) can be obtained. The model for stiffness of aggregate is introduced to fit the relation between the coarse aggregate stiffness and the shrinkage of concrete.

In the part of verification of aggregate stiffness, the data of autogenous shrinkage of concrete (ε_{conc}) was obtained from Deesawangnade as well as the free shrinkage of paste in concrete (ε_{po}). Fig. 9.1 illustrates the test results of autogenous shrinkage of paste with water to cement ratio of 0.30 and 0.40.

The proposed model for stiffness of aggregate was utilized to compute the stiffness and compared with the results indirectly derived from back analysis of the tested shrinkage using two-phase model for shrinkage of concrete. Fig. 9.2 to Fig. 9.6 demonstrate the comparison results.

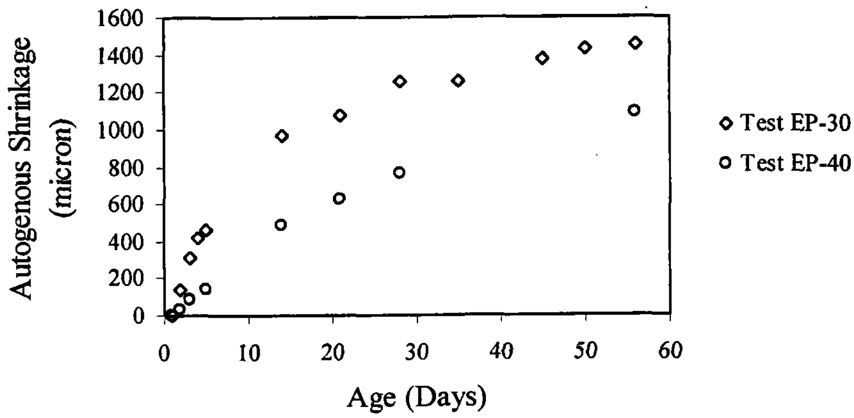

Fig. 9.1 Test results of autogenous shrinkage of paste with water to cement ratio of 0.30 and 0.40

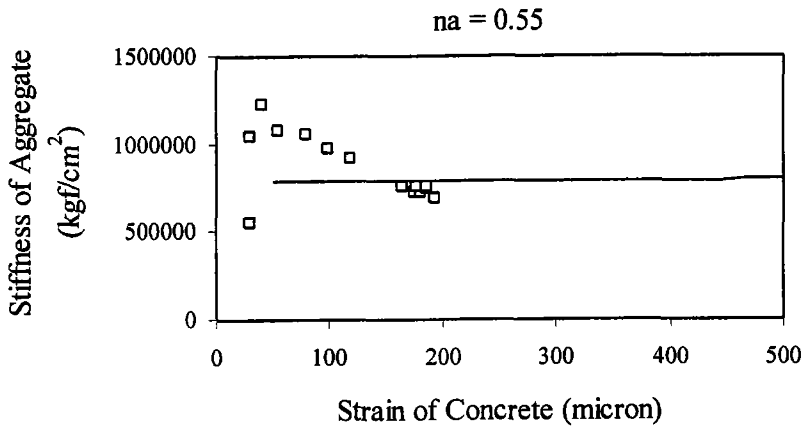

Fig. 9.2 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 1.0 and water to cement ratio of 0.30 (G_{max}=20mm.)

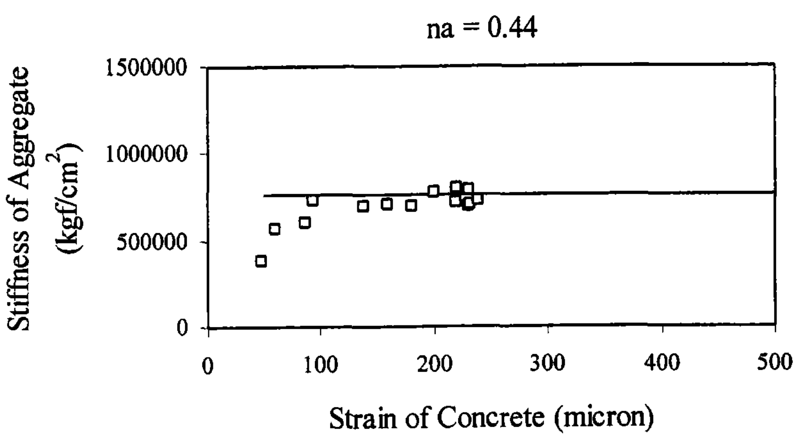

Fig. 9.3 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 0.80 and water to cement ratio of 0.30 (G_{max}=20mm.)

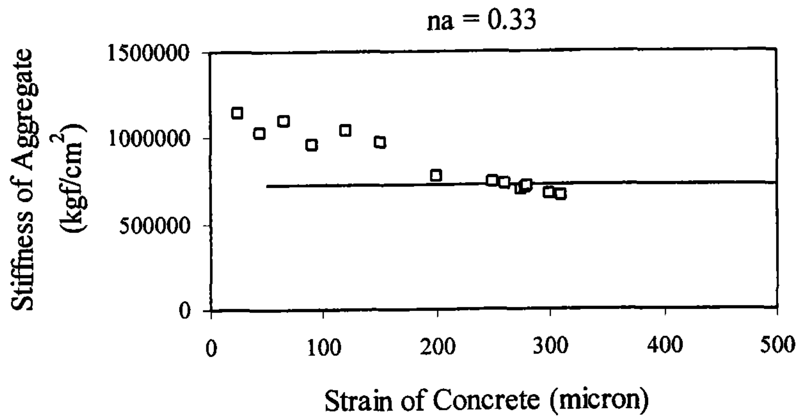

Fig. 9.4 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 0.60 and water to cement ratio of 0.30 (G_{max}=20mm.)

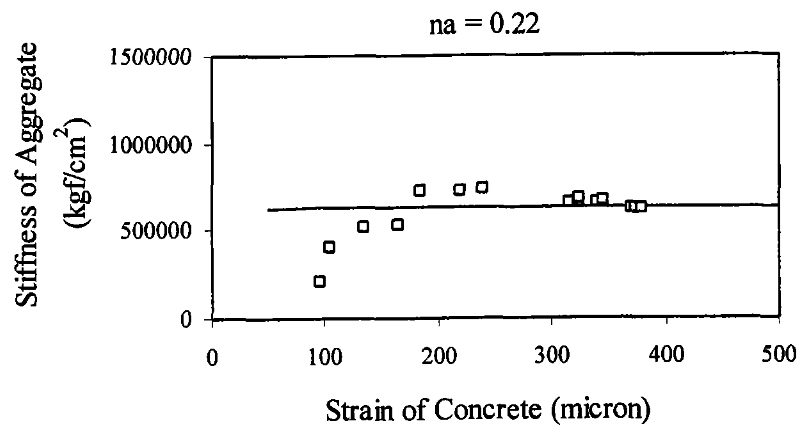

Fig. 9.5 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 0.40 and water to cement ratio of 0.30 (G_{max}=20mm.)

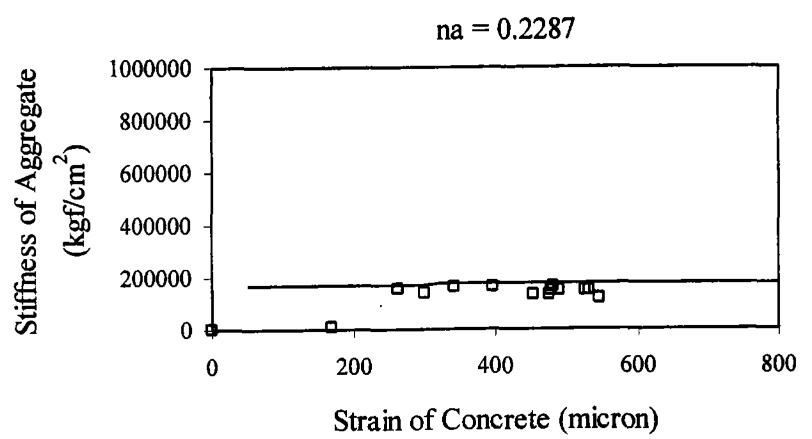

Fig. 9.6 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 0.40 and water to cement ratio of 0.30 (G_{max}=8mm.)

9.1.2 Stiffness of fine aggregate

The tests were performed on mortar specimens with the volume concentration ratio of fine aggregate ($n_s/n_{s,max}$) equal to 0.85, 0.80, 0.70, 0.65, 0.60, 0.50, 0.40, which are equivalent to the volume concentration of fine aggregate (n_s) equal to 0.5695, 0.536, 0.469, 0.4355, 0.402, 0.335, 0.268, respectively. In order to fine the stiffness of fine aggregate, the procedures which were need to fine the stiffness of fine aggregate are the same procedures as that of coarse aggregate. The verification is performed on mortar having water to cement ratios equal to 0.30 and 0.40. The comparisons of fine aggregate stiffness from back analysis test results and proposed model are demonstrated in Fig. 9.7 to Fig. 9.14.

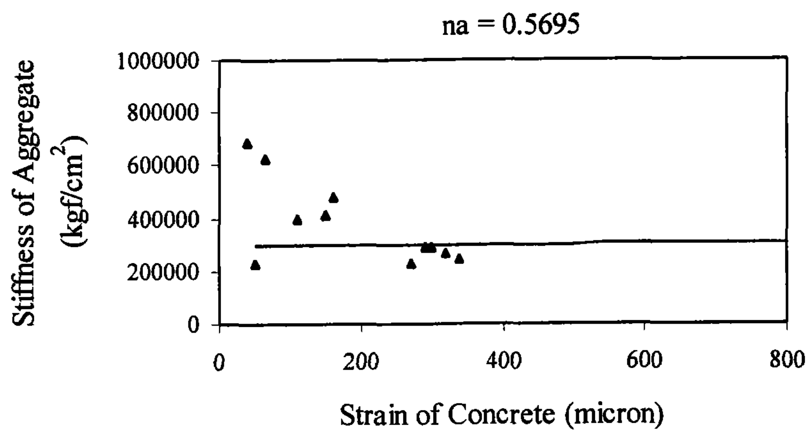

Fig. 9.7 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.85 and water to cement ratio of 0.30

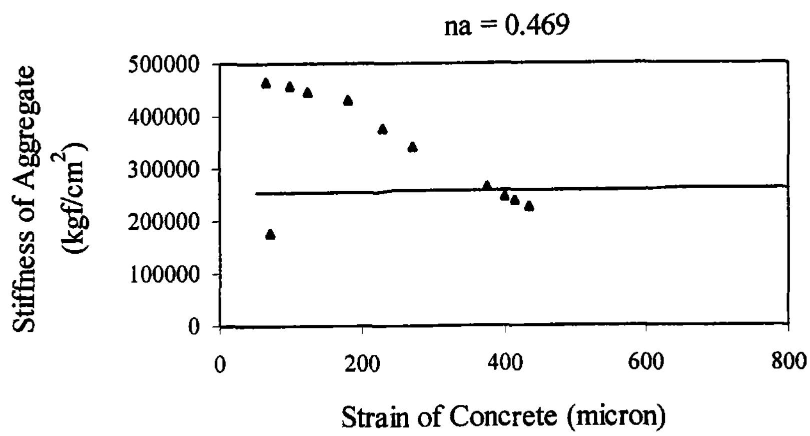

Fig. 9.8 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.70 and water to cement ratio of 0.30

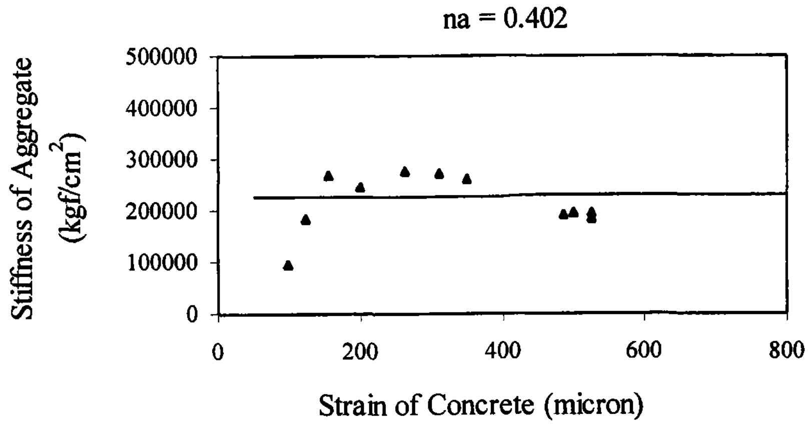

Fig. 9.9 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.60 and water to cement ratio of 0.30

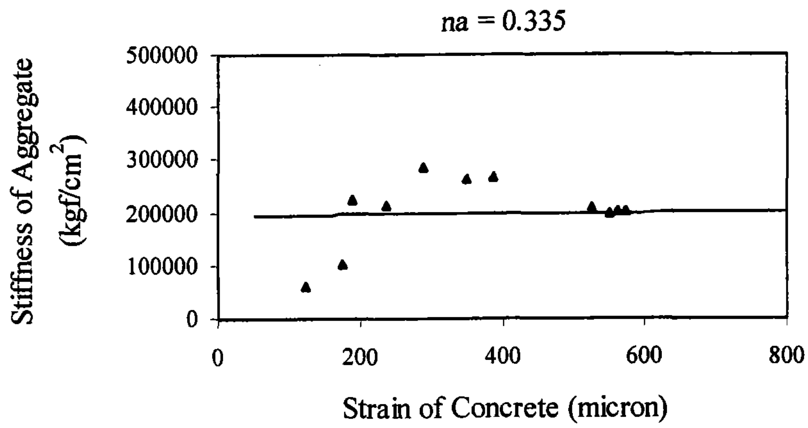

Fig. 9.10 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.50 and water to cement ratio of 0.30

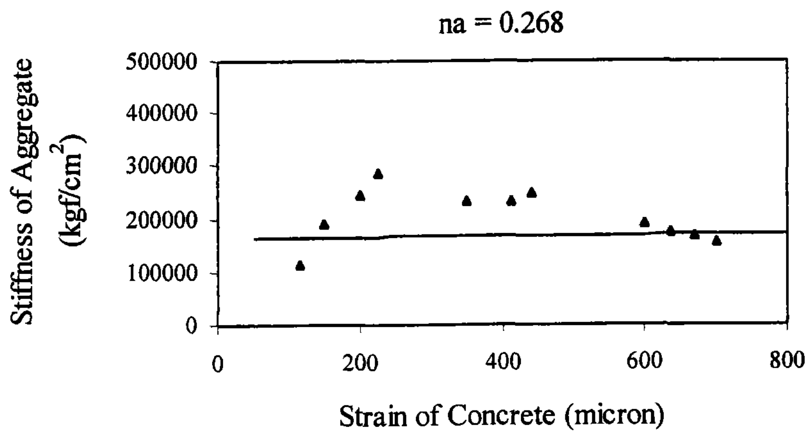

Fig. 9.11 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.40 and water to cement ratio of 0.30

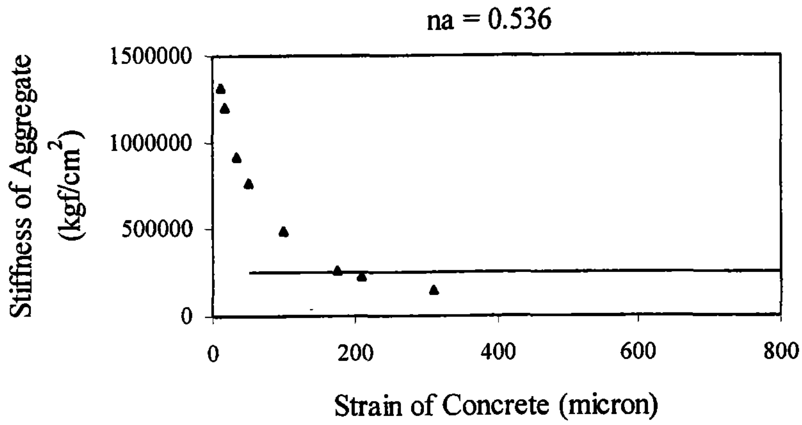

Fig. 9.12 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.80 and water to cement ratio of 0.40

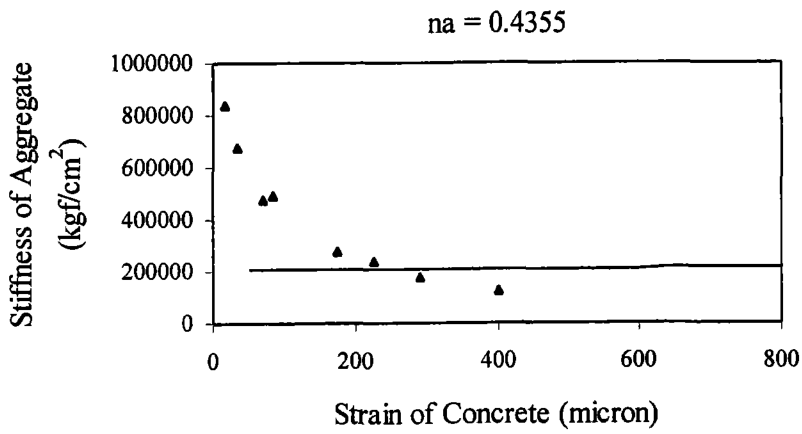

Fig. 9.13 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.65 and water to cement ratio of 0.40

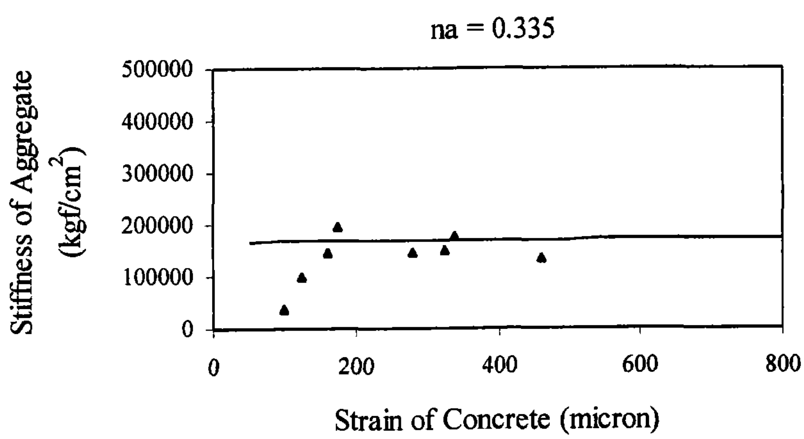

Fig. 9.14 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of mortar with volume concentration ratio ($n_s/n_{s,max}$) of 0.50 and water to cement ratio of 0.40

9.1.3 Stiffness of binary mixture

Normally, concrete is composed of binary mixture of aggregates, one component is coarse aggregate and the other is fine aggregate. The maximum size of coarse aggregate is 20 mm. The proportions of binary mixture, which were performed in this study, are the sand to total aggregates ratio and volume concentration ratio of agggregate. Sand to total aggregates ratios by weight (s/a) are equal to 0.25, 0.50, and 0.75. Each type of binary mixture has two different volume concentration ratio ($n_a/n_{a,max}$) which are 0.50 and 0.70. The details of mixes are shown in Table B.1. The verification was performed on concrete having water to cement ratio equal to 0.30. The comparisons of aggregate stiffness of binary mixture from back analysis test results and proposed model are shown in Fig. 9.15 to Fig. 9.20.

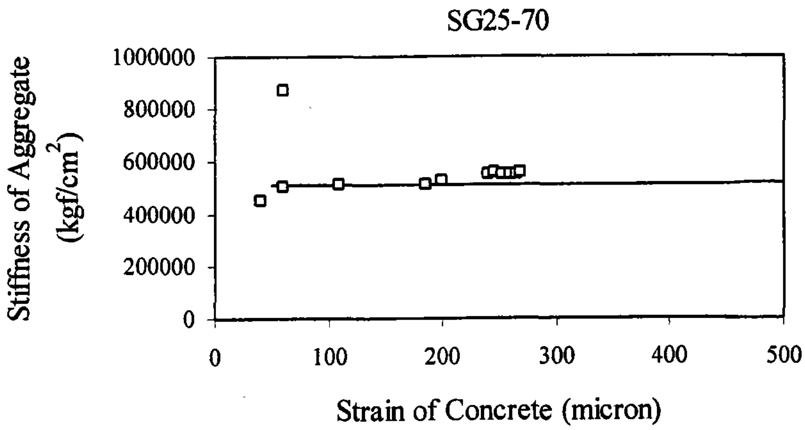

Fig. 9.15 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.25, and water to cement ratio of 0.30

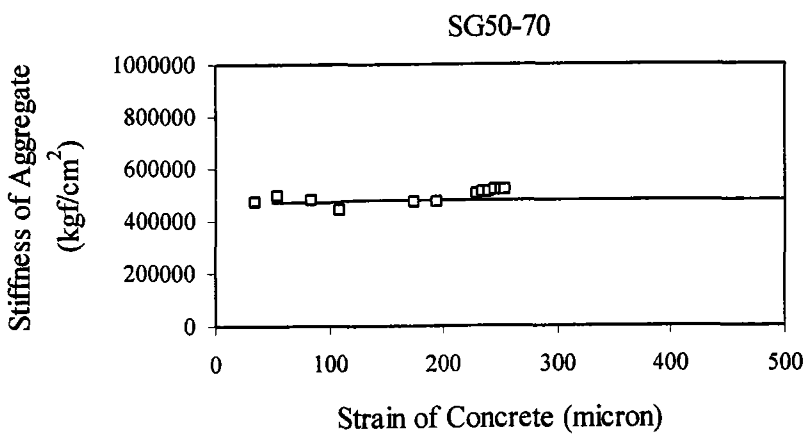

Fig. 9.16 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.50, and water to cement ratio of 0.30

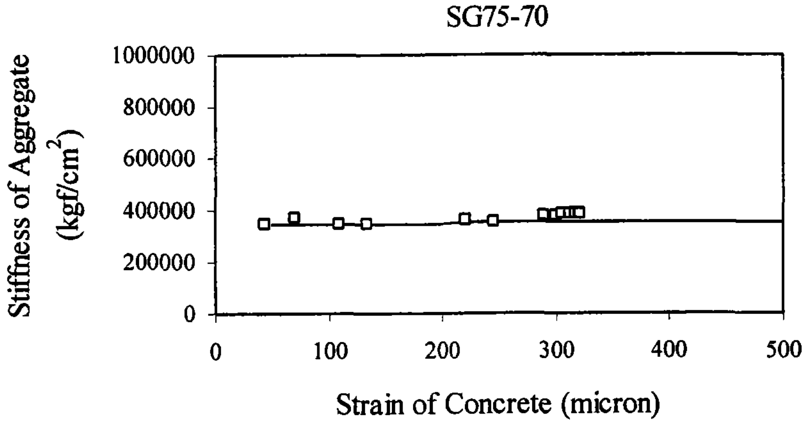

Fig. 9.17 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.75, and water to cement ratio of 0.30

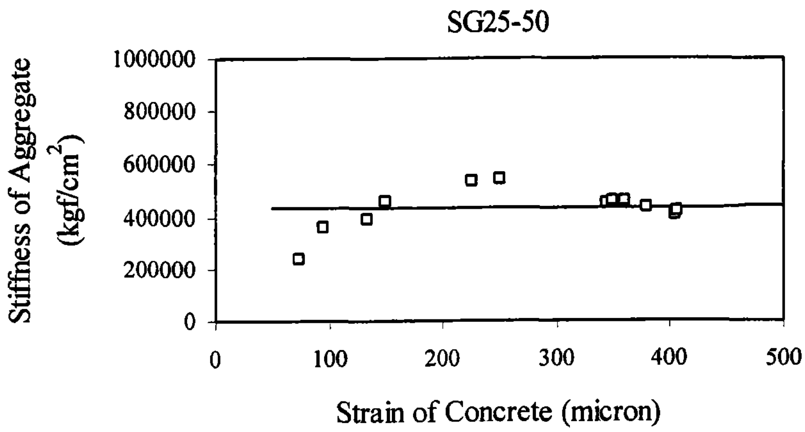

Fig. 9.18 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.25, and water to cement ratio of 0.30

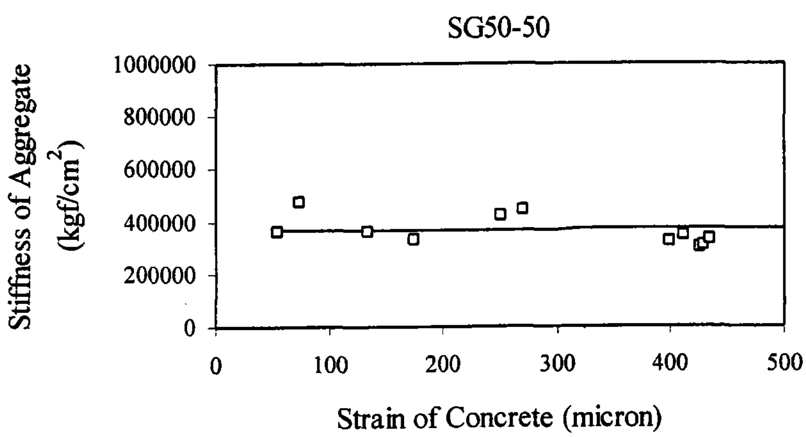

Fig. 9.19 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.50, and water to cement ratio of 0.30

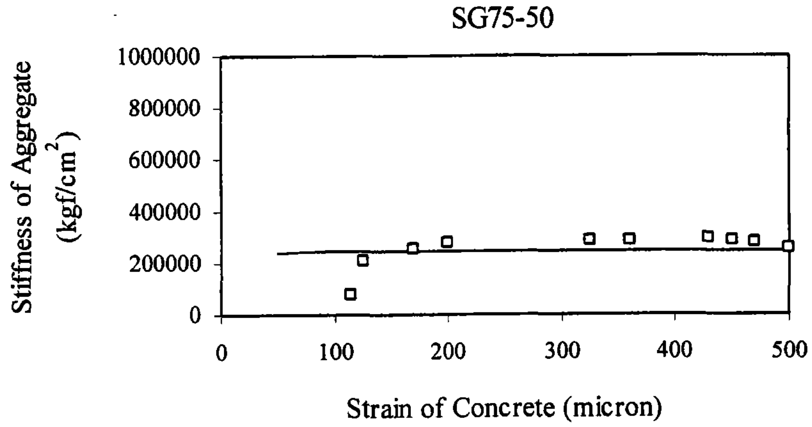

Fig. 9.20 Comparison between back analysis of the tested shrinkage and the aggregate stiffness model of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.75, and water to cement ratio of 0.30

9.2 Verification of Autogenous Shrinkage of Paste

Free shrinkage of paste in concrete is one of the parameters to obtain the shrinkage of concrete from a two-phase model. The experiments are conducted on paste with different type of cement and fly ash, water to binder ratio, and curing temperature for obtaining the autogenous shrinkage of paste. The results obtained from paste shrinkage test and the model for autogenous shrinkage of paste are compared in Fig. 9.21 to Fig. 9.30.

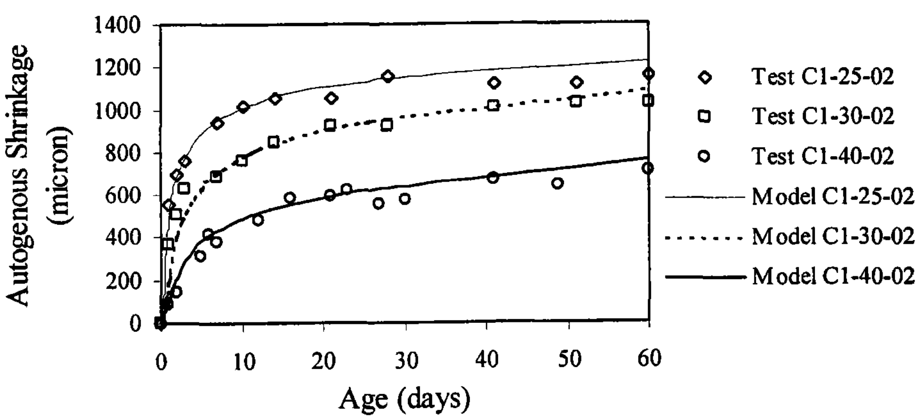

Fig. 9.21 Comparisons between test results of autogenous shrinkage and the model of paste with type 1, type 3, and type 5 cement in case of w/c = 0.30, at 25°C, 80% R.H.

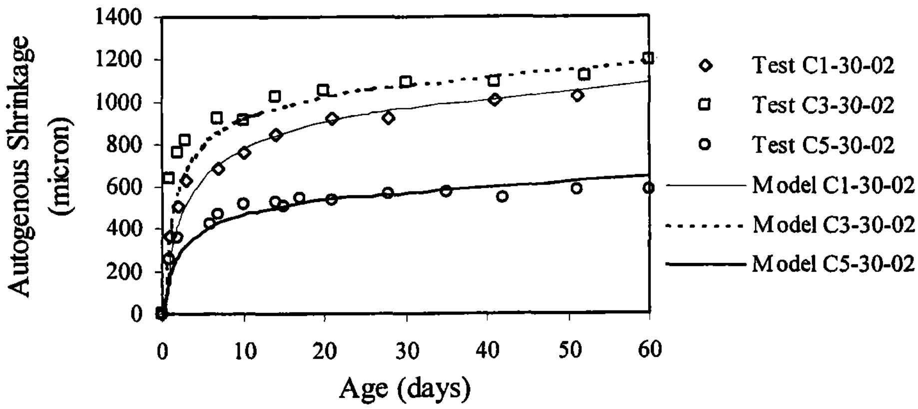

Fig. 9.22 Comparisons between test results of autogenous shrinkage and the model of paste with type 1 cement with fineness of 3190, 5570, and 7430 cm^2/g in case of w/c = 0.30, at 25°C, 80% R.H.

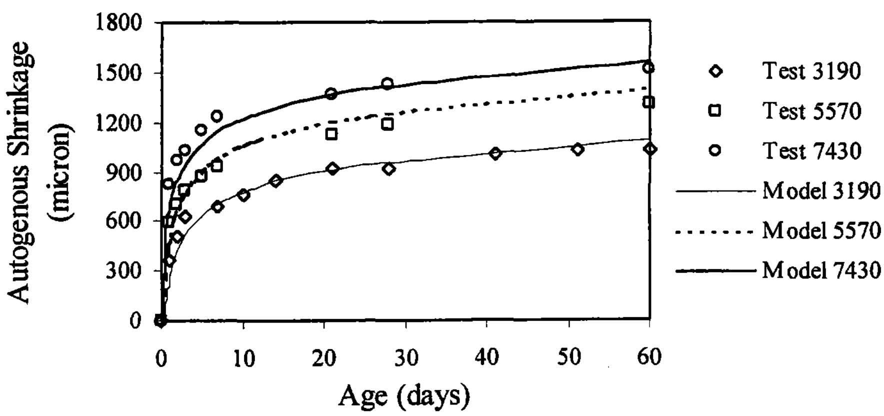

Fig. 9.23 Comparisons between test results of autogenous shrinkage and the model of paste with type 1 cement in case of w/c = 0.25, 0.30, and 0.40 at 25°C, 80% R.H.

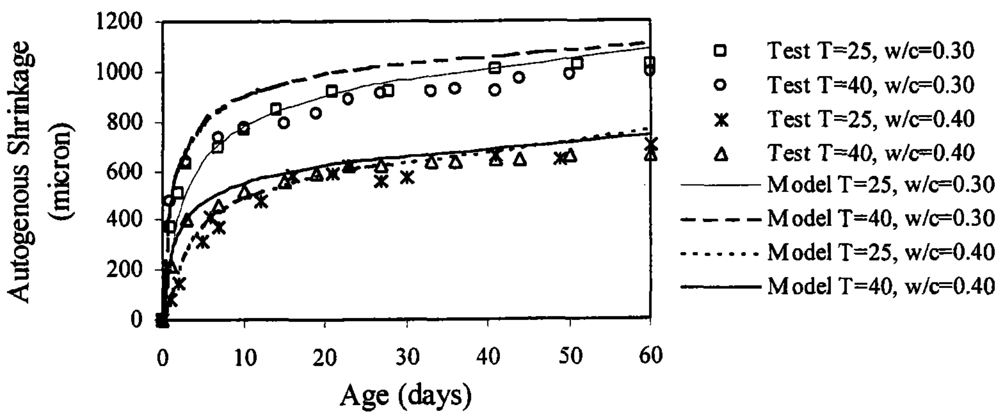

Fig. 9.24 Comparisons between test results of autogenous shrinkage and the model of paste with type 1 cement with curing temperature of 25°C and 40°C in case of w/c = 0.30 and 0.40 at 80% R.H.

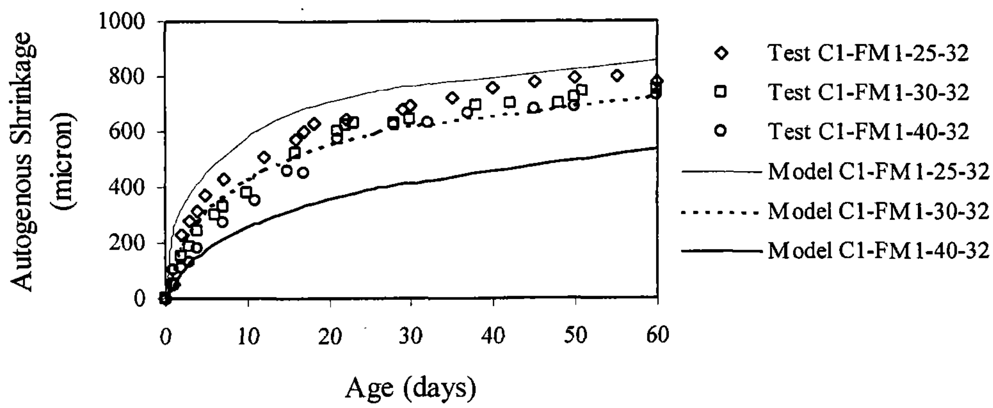

Fig. 9.25 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 30% FM1 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

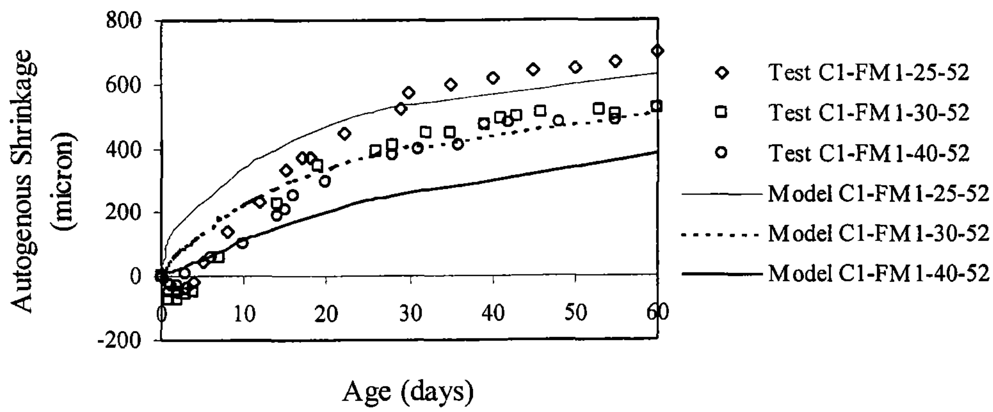

Fig. 9.26 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 50% FM1 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

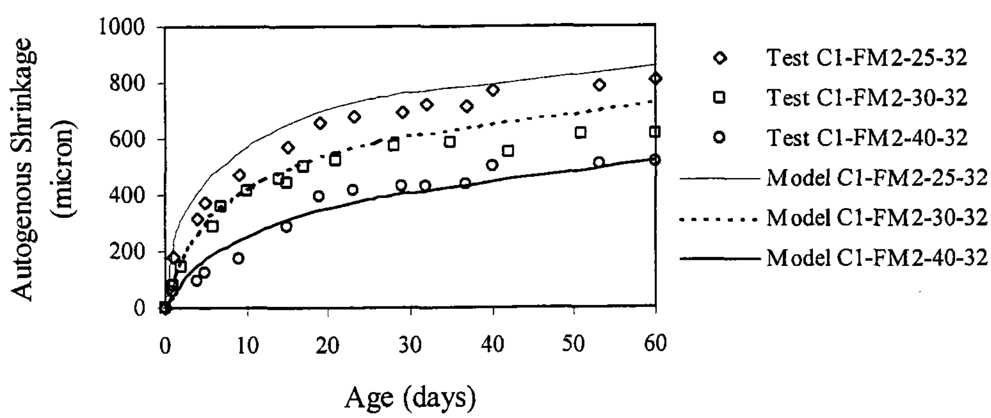

Fig. 9.27 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 30% FM2 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 80% R.H.

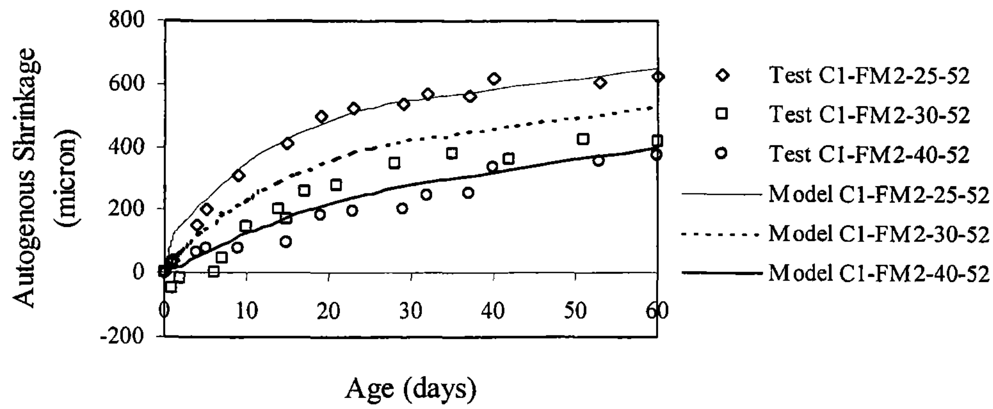

Fig. 9.28 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 50% FM2 in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 80% R.H.

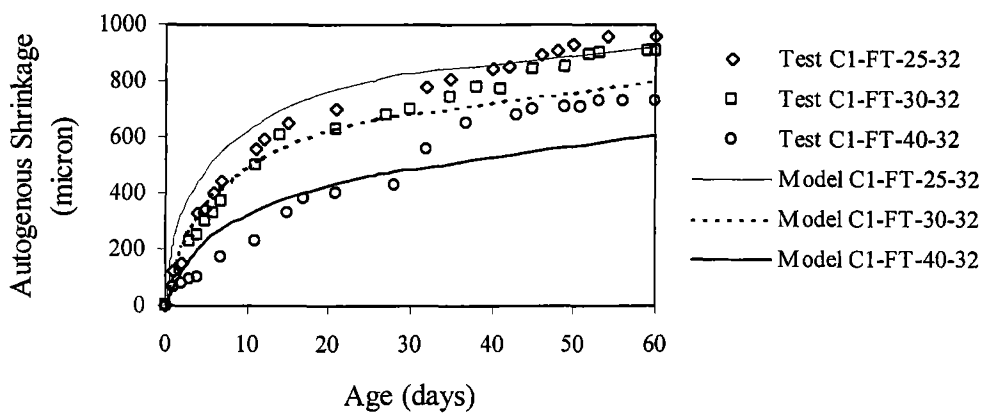

Fig. 9.29 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 30% FT in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

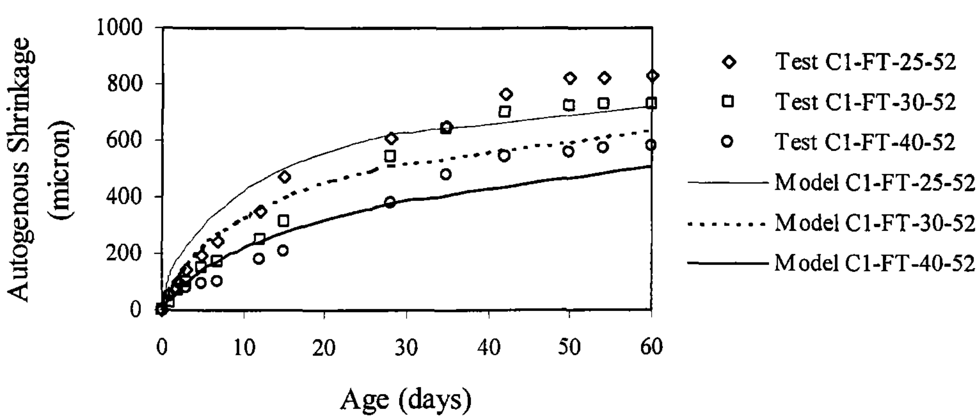

Fig. 9.30 Comparisons between test results and the model of autogenous shrinkage of paste with type 1 cement and replaced by 50% FT in case of w/b = 0.25, 0.30, and 0.40 at 25°C, 60% R.H.

9.3 Verification of Autogenous Shrinkage of Mortars and Concrete

The verification of autogenous shrinkage of no-fine concrete, mortars, and concrete is presented in form of comparison between experimental data and computed results from the model.

9.3.1 Autogenous shrinkage of no-fine concrete

Tests were conducted on no-fine concrete with water to cement ratio of 0.30 and under sealed condition. The verification was performed on no-fine concrete specimens with the volume concentration ratio of 1.0, 0.80, 0.60, and 0.40. Eq. (5.12) was employed to calculate the strain of concrete shrinkage (ε_{conc}) from free shrinkage strain (ε_{po}) proposed by the model in Chapter 8. The stiffness model of coarse aggregate in Chapter 6 was used in the prediction of no-fine concrete shrinkage strain (ε_{conc}). The experimental results and analytical results from the autogenous shrinkage model are compared in Fig. 9.31 and Fig. 9.32.

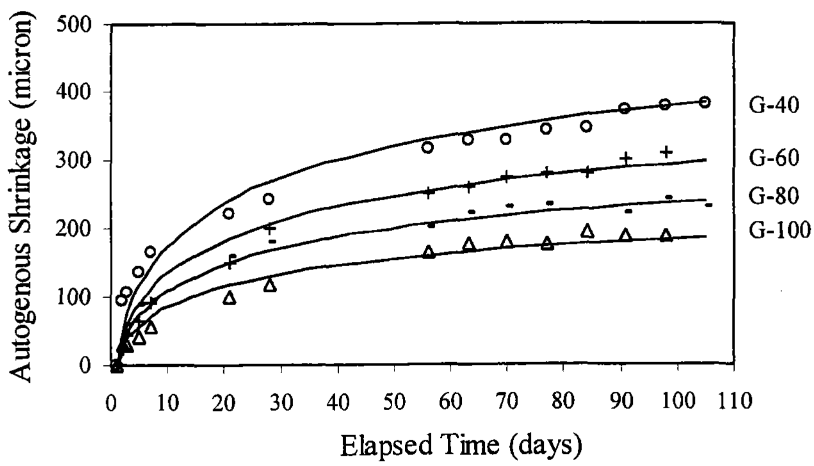

Fig. 9.31 Comparisons between test results and the model of autogenous shrinkage of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 1.0, 0.80, 0.60, and 0.40, and water to cement ratio of 0.30 (G_{max}=20 mm.)

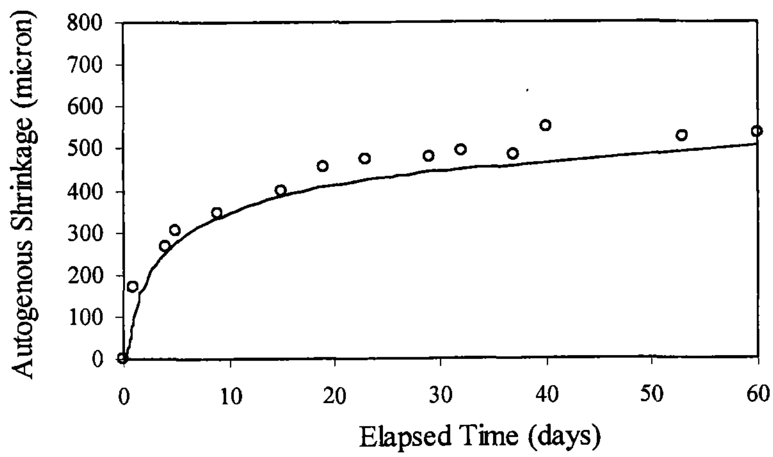

Fig. 9.32 Comparisons between test results and the model of autogenous shrinkage of no-fine concrete with volume concentration ratio ($n_g/n_{g,max}$) of 0.40, and water to cement ratio of 0.30 (G_{max}=8 mm.)

9.3.2 Autogenous shrinkage of mortars

The verification was conducted on mortar specimens with the relative volume concentration ratio of fine aggregate ($n_s/n_{s,max}$) equal to 0.85, 0.80, 0.70, 0.65, 0.60, 0.50, and 0.40. The tests of autogenous shrinkage were conducted on water to cement ratios equal to 0.30 and 0.40. The procedures used to find autogenous shrinkage of mortar are the same as that of no-fine concrete. The test and analytical results of autogenous shrinkage of mortars are compared in Fig. 9.33 and Fig. 9.34.

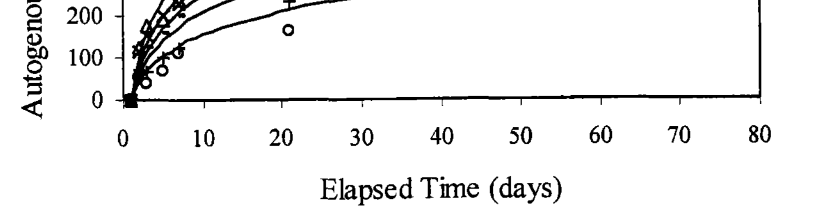

Fig. 9.33 Comparisons between test results and the model of autogenous shrinkage of mortars with volume concentration ratio ($n_s/n_{s,max}$) of 0.85, 0.70, 0.60, 0.50, and 0.40, and water to cement ratio of 0.30

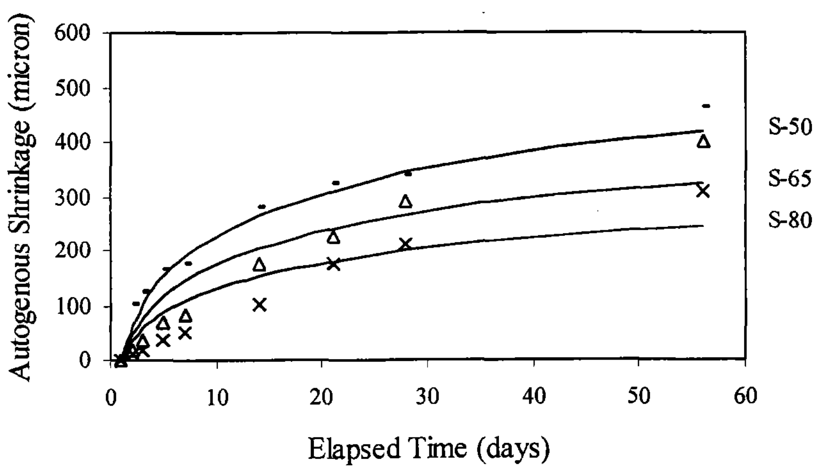

Fig. 9.34 Comparisons between test results and the model of autogenous shrinkage of mortars with volume concentration ratio ($n_s/n_{s,max}$) of 0.80, 0.65, and 0.50, and water to cement ratio of 0.40

9.3.3 Autogenous shrinkage of concrete

The verification was performed on concrete specimens having different sand to total aggregates by weight (s/a) and volume concentration ratio of total aggregates ($n_a/n_{a,max}$) with water to cement ratio of 0.30. The procedures used to find autogenous shrinkage of concrete with binary mixture of aggregate were the same as those of mortars and no-fine concrete. The experimental results and analytical results from the autogenous shrinkage model are compared in Fig. 9.35 and Fig. 9.36.

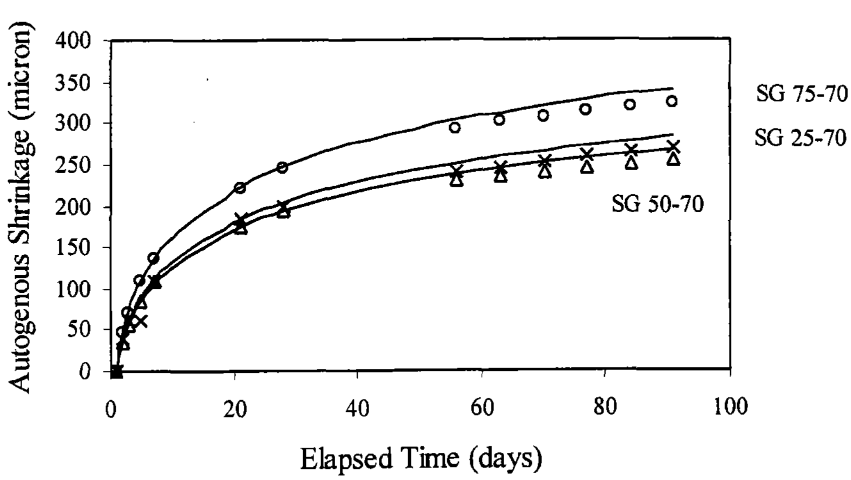

Fig. 9.35 Comparisons between test results and the model of autogenous shrinkage of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.70, sand to total aggregates ratio (s/a) of 0.25, 0.50, and 0.70, and water to cement ratio of 0.30

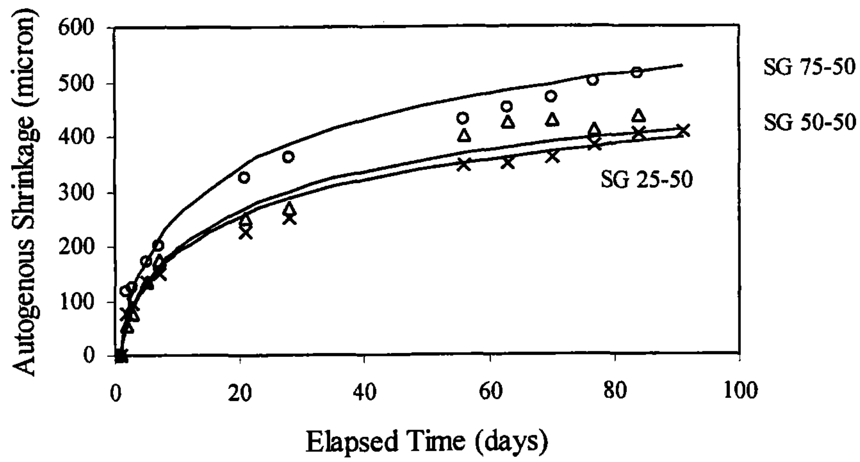

Fig. 9.36 Comparisons between test results and the model of autogenous shrinkage of concrete with volume concentration ratio ($n_a/n_{a,max}$) of 0.50, sand to total aggregates ratio (s/a) of 0.25, 0.50, and 0.70, and water to cement ratio of 0.30

9.4 Verification of Drying Shrinkage of Concrete

In order to verify the versatility of concrete shrinkage model, data obtained from various researches were adopted. The procedure used to find drying shrinkage were the same as that of autogenous shrinkage. The comparisons of experimental results and analytical results are shown in Fig. 9.37 to Fig. 9.43. The details of mix proportions are shown in Table B.2 and Table B.3.

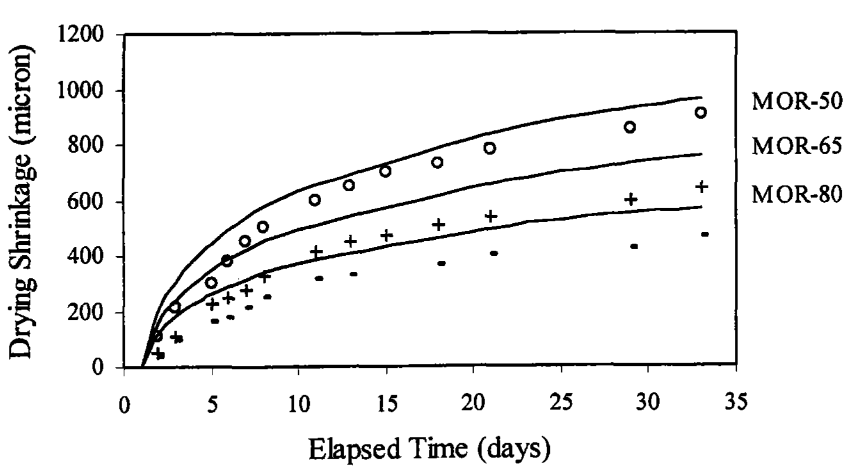

Fig. 9.37 Comparisons between test results and the model of drying shrinkage tested by Deesawangnade (1994) (specimen size is 40×40×160 mm, 27 days water curing)

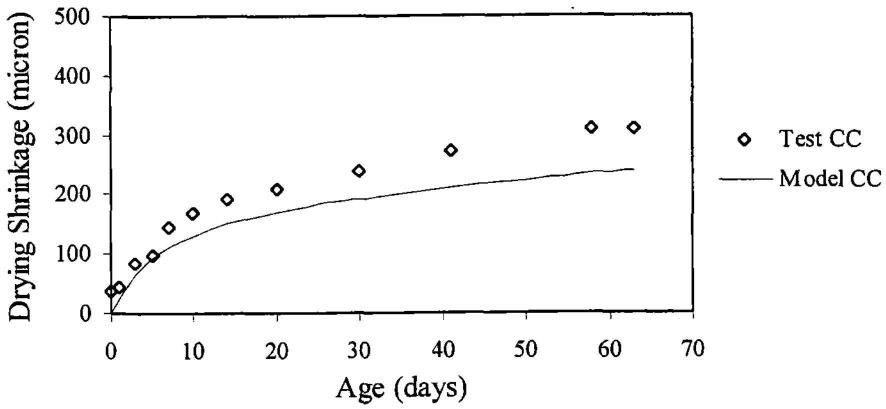

Fig. 9.38 Comparisons between test results and the model of drying shrinkage tested by Deesawangnade (1994) (specimen size is 100×100×500 mm, 28 days water curing)

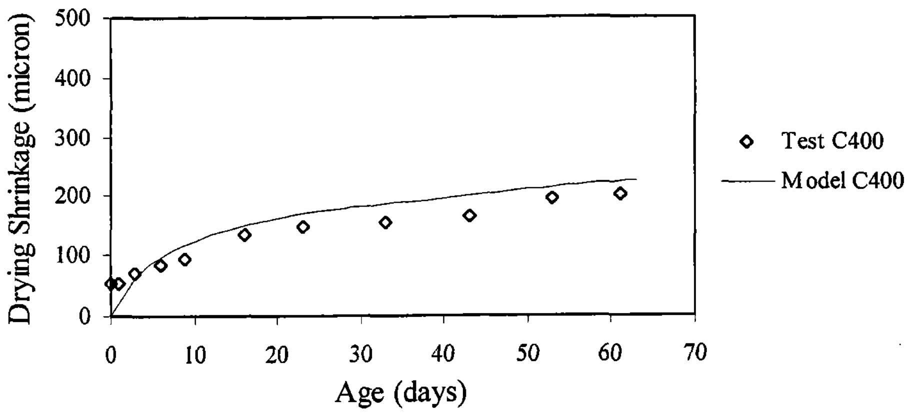

Fig. 9.39 Comparisons between test results and the model of drying shrinkage tested by Deesawangnade (1994) (specimen size is 100×100×500 mm, 28 days water curing)

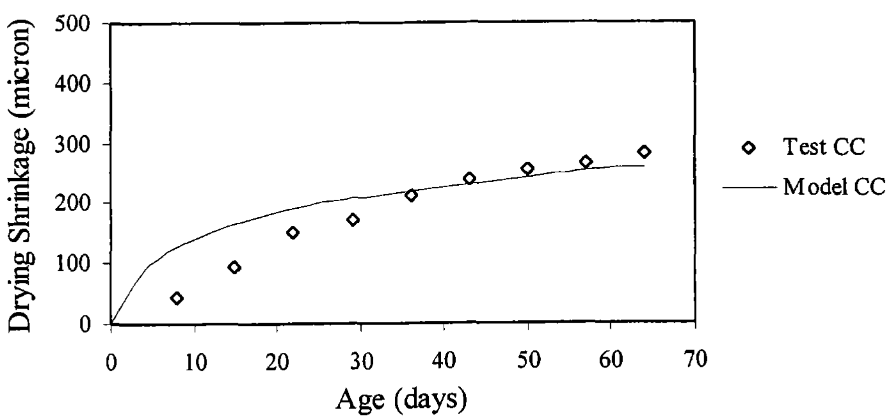

Fig. 9.40 Comparisons between test results and the model of drying shrinkage tested by Srichoo (1997) (specimen size is 100×100×500 mm, 27 days water curing)

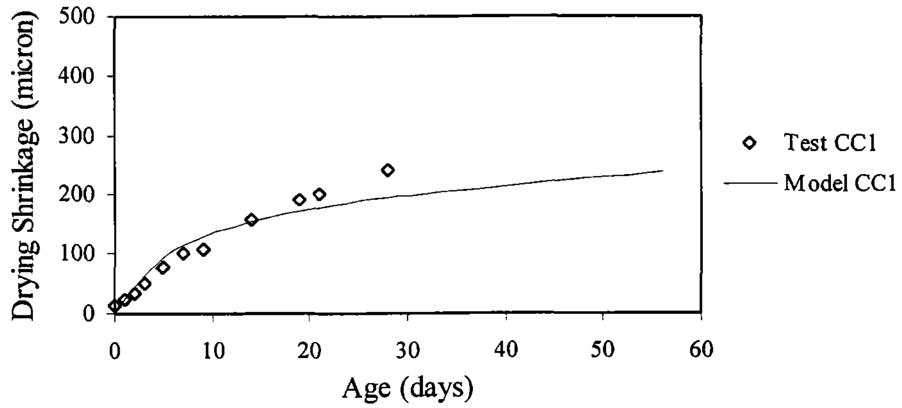

Fig. 9.41 Comparisons between test results and the model of drying shrinkage tested by Sayamipuk (1994) (specimen size is 100×100×500 mm, 28 days water curing)

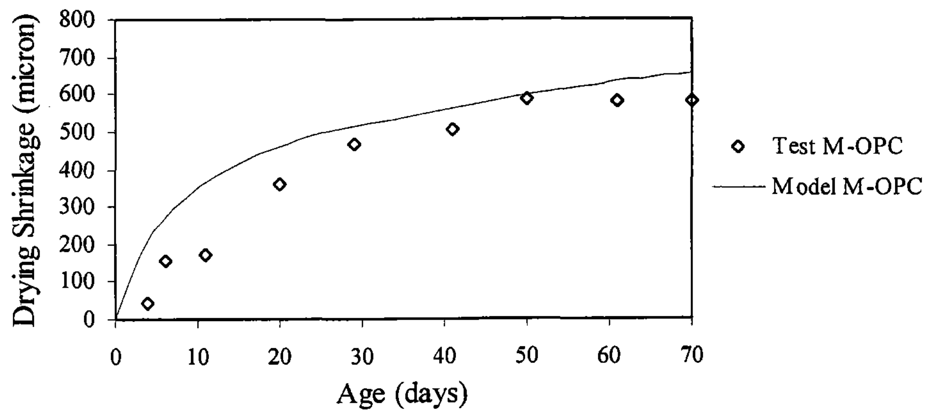

Fig. 9.42 Comparisons between test results and the model of drying shrinkage tested by Tassanakosol (1999) (specimen size is 25×25×285 mm, 28 days water curing)

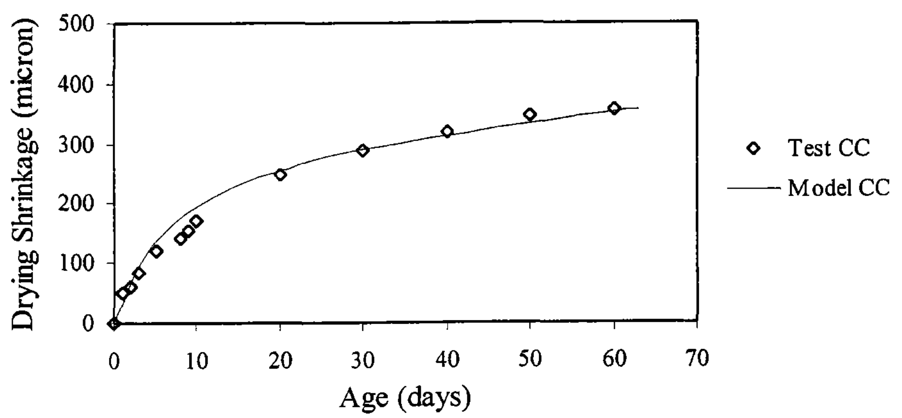

Fig. 9.43 Comparisons between test results and the model of drying shrinkage tested by Suzuki (1993) (specimen size is 100×100×500 mm, 7 days water curing)