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Long-Term Performance of High Strength Concrete

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Abstract

This paper describes an experimental investigation of how time-dependent deformations of high strength concretes are affected by maximum size of coarse aggregate, curing time, and relatively low sustained stress level. A set of high strength concrete mixes, mainly containing two different maximum sizes of coarse aggregate, have been used to investigate drying shrinkage and creep strain of high strength concrete for 7 and 28-day moist cured cylinder specimens. Based upon one-year experimental results, drying shrinkage of high strength concrete was significantly affected by the maximum size of coarse aggregate at early age, and become gradually decreased at late age. The larger the maximum size of coarse aggregate in high strength concrete shows the lower the creep strain. The prediction equations for drying shrinkage and creep coefficient were developed on the basis of the experimental results, and compared with existing prediction models.

Keywords: high strength concrete (HSC), creep, drying shrinkage, maximum size of coarse aggregate

1. Introduction

Creep and drying shrinkage are probably two most disadvantageous time-dependent properties of concretes because they are in direct relation to the proper use of concretes. The uses of high strength concrete (HSC) have been increased in building structures because HSC achieves certain desirable requirements such as become taller and simpler with the reduced sections of concrete structural elements. Therefore, time-dependent properties of high strength concrete become very important to predict in-service behaviors of HSC structures undergoing a long-term sustained load.[1-3)] A large number of investigations related to the time-dependent behaviors of concrete have been performed on normal weight concrete and HSC with a variety of variables such as temperature, concrete composition, relative humidity, water-cementitious ratio, curing type, and curing ages of concrete. Over the years, these variables that influence creep and shrinkage were established even though these phenomena can not be separated from each other. We summarize the results from those few investigations which focused on the drying shrinkage and creep of concretes.

ACI Committee 209[6)] recommended an equation for predicting unrestrained drying shrinkage strain at any time with normal-strength concrete for 7-day moist cured concrete as follows:

$$(\varepsilon_{sh})_t = \frac{t}{35+t}(\varepsilon_{sh})_u \tag{1}$$

Where, $(\varepsilon_{sh})_t$= shrinkage strain at any time t; t= time in days; $(\varepsilon_{sh})_u$=780 x 10^{-6} in/in.(ultimate shrinkage strain). The value of $(\varepsilon_{sh})_u$ can be modified by the correction factor for conditions other than the standard conditions such as the effects of initial moist curing, ambient relative humidity, size or volume surface ratio, temperature, and concrete composition, and the effect of coarse aggregate in not taken into account.[4)] In addition, ACI Committee 209 recommended an equation for creep coefficient υ_t with normal-strength concrete under standard conditions as follows:

$$\upsilon_t = \frac{t^{0.60}}{10+t^{0.60}}\upsilon_u \tag{2}$$

Where, =creep coefficient at any time t; t= time in days after sustained loading; =2.35 (ultimate creep coefficient). The value can be modified by the correction

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factor for conditions other than the standard conditions such as the effects of loading age, initial moist curing, ambient relative humidity, size or volume surface ratio, temperature, and can be determined by fitting the data obtained from tests performed in accordance with the ASTM C512.[10] Also these two equations apply to sand lightweight and all light weight concretes. In 1990, the Euro-International Concrete Committee adopted new guidelines (CEB 90) for the prediction of drying shrinkage based on experimental results and analysis of available research data as follows:[12-14]

$$\varepsilon_{cs}(t-t_s) = (\varepsilon_{cso})\beta_s(t-t_s) \tag{3}$$

$$\varepsilon_{cso} = \varepsilon_s(f_{cm})(\beta_{RH}), \text{ and}$$

$$\varepsilon_s(f_{cm}) = [160 + 10\beta_{sc}(9 - \frac{f_{cm}}{1450})]\text{x}10^{-6}$$

Where, $\varepsilon_{cs}(t-t_s)$ = shrinkage strain between time t and t_s (in/in), ε_{cso} = Notional shrinkage coefficient, $\beta_s(t-t_s)$ = equation describing development of shrinkage with time, $\varepsilon_s(f_{cm})$ = factor to allow for the effect of concrete strength on shrinkage, β_{RH} =coefficient to allow for the effect of relative humidity on the notional shrinkage coefficient (ε_{cso}), β_{sc} = coefficient depending on type of cement, f_{cm} =mean 28-day concrete compressive strength (psi)

Khan, Cook and Mitchell[5] investigated creep, shrinkage and thermal strains in normal (30 MPa), medium (70 Mpa) and high strength concrete (100 MPa) during hydration at early age. The dimensions of the tested concrete cylinder specimens were 100 mm x 200 mm with the crushed limestone maximum coarse aggregate size of 7 mm for the HSC and 0.25 water/cement ratio. Two different curing methods, sealed curing and air-dried curing, were used. The applied stress/strength ratios at the time of loading were 5-9.6 % for the HSC at early ages. The test results show that HSC exhibits greater shrinkage and thermal strains than medium strength concrete, which in turn shows greater strains than normal strength concrete for both sealed and air-dried conditions. It should be noted that the authors used different cement types and maximum aggregate size at each category of concrete strength to compare shrinkage, creep and thermal strains.

Mokhtarzadeh A. and French C.,[7] investigated time-dependent properties such as creep, shrinkage and water absorption of high-strength concrete. All of the specimens contained a 445 kg/m^3 (750 lb/yd^3) of cementitious material and had a 0.3 water/cement ratio. Cementitious material compositions included ASTM C 150[8] Type I and II Portland cement (reference mixture), and combinations of 20% ASTM C618[11] Class C fly ash and 7.5% silica fume, replacement by weight of cement. Three coarse aggregate types, two limestone, granite and river gravel, were used with a 0.5% of absorption capacity of sand. For creep tests, two unsealed 100 mm x 280 mm cylinder concrete specimens were stacked in series on the upper base plate of a creep frame, and loaded at a given stress for 380 days. The creep coefficient of high strength concrete from these creep tests was calculated, and compared to ACI 209 Code Model. The results of fitted creep coefficient data on ACI 209 Code Model were closed, and comparable to the ranges presented in ACI 209 Code Model. The range of ultimate creep coefficients predicted in this study varied between 0.92 to 2.46 as compared with the 1.30 to 4.15 range reported by ACI 209 Code Model for normal strength concrete. Shrinkage tests were conducted to investigate the effects of several variables such as the cementitious material composition, aggregate type and curing condition. Test results show that the shrinkage strain of HSC made with round river gravel is greater than those of HSC made with crushed aggregates, and the average value of shrinkage strains of moist cured specimens after 380 days of drying were approximately 63-73% of the shrinkage strain values of ACI 209 Code Model. Based on the test data, the following equation was suggested for predicting shrinkage strain of high strength concrete at any time.

$$(\varepsilon_{sh})_t = \frac{t}{45+t}(530\text{x}10^{-6} \text{ in/in}) \tag{4}$$

Huo, Al-Omaish and Tadros[4] proposed the revised formulas for shrinkage strain and creep coefficient for high-performance concrete (HPC) with local materials from Nebraska, USA. The shrinkage and creep test specimens were 100 mm x 100 mm x 600 mm prisms tested at average room temperature of 18 ^{0}C (65 ^{0}F) and an average relative humidity of 40%. Based on the results from specimens cured for 7 and 14 days, shrinkage strains and creep coefficient of HPC were measured in three groups of specimens, and compared with the ACI 209 Code Model by the statistical analysis.

It was concluded that the shrinkage strains and creep coefficient of HPC were lower than those of conventional concretes and that the prediction equations for shrinkage strains and creep coefficients in the ACI 209 Code Model overestimate the actual shrinkage strains and creep coefficients of HPC. The objective of this investigation is to deal with creep and drying shrinkage deformations of high strength concrete take into account the effects of maximum size of coarse aggregate (MSCA), curing time, relatively low stress level because these time-dependent deformations become very important to predict the variations of the strength and structural behaviors in high strength concrete structures.

2. Experimental program

2.1 Materials and mix proportioning

The materials used in the present investigation were Type I Portland cement and 30% class C fly ash for mineral admixtures to replace partial cement. The chemical composition and physical properties of cement and fly ash are given in Table 1. The maximum sizes of coarse aggregates were crushed limestone with a density of 1.52 x 10^3 kg/m^3 and its maximum size is 25.4 mm, and a density of 1.47 x 10^3 kg/m^3 and its maximum size is 9.5 mm, respectively. The fine aggregate was natural sand with a specific gravity of 2.63 and a fineness modulus of 2.6. Also, a high-range water-reducing (HRWR) admixture (superplasticizer) meeting ASTM C494[9)] requirements for a Type F admixture was used to keep the water/cement ratio of HSC. Two different HSC mixtures were investigated: Mix (I) contained 9.5 mm (3/8 in) maximum size of aggregate and the water/cementitious ratio was 0.32; Mix (II) contained 25.4 mm (1.0 in) maximum size of aggregate and water/cementitious was 0.29.

The mix proportioning for Mix (I) and (II) are given in Table 2. Test cylinder specimens made in mold by vibration at temperature of 20 ± 1.5 ^{0}C. The specimens were demolded at one day and then cured in the moisture room at a temperature of 23 ± 0.5 ^{0}C and 100 % relative humidity. A total of twenty cylinder specimens of HSC were investigated in this study, all of which had nominal dimensions of 305 mm (12 in) in height and 152 mm (6 in) in diameter.

2.2 Drying shrinkage test

Drying shrinkage tests were carried out for 7-day and 28-day moisture cured cylinder specimens of Mix (I) and (II), respectively. All specimens were located in the environmentally controlled room maintained temperature at 23 ± 0.5^{0}C and 50% relative humidity. A total of 8 shrinkage specimens in two mixtures were investigated.

Brass inserts were attached on the surface of specimens at a spacing of about 250 mm (10 in.) in the longitudinal direction. Four readings of shrinkage strains were taken from each specimen using a multi-position Strain Gauge (MPSG) with a dial indicator reading up to 0.0025 mm. The MPSG is designed for use in measuring relative displacements between gauge points of 50 mm (2 in), 100 mm (4 in), 150 mm (6 in), 200 mm (8 in) and 254 mm (10 in.)..

2.3 Creep test

Creep tests were conducted on the 28-day moisture cured sealed and unsealed cylinder specimens of HSC in accordance with the ASTM C-512 [10]. The creep specimens had Brass inserts in the same manner at the shrinkage specimens. The 28-day moisture cured cylinder axial compressive strength of HSC was used for calculating the applied load. The obtained axial average compressive strengths of HSC at given time are shown in Table 3.

Creep test specimens were loaded in a special creep rack. Each creep rack contained three cylinder specimens. The surface of the middle specimen was sealed while the other two specimens were unsealed. A hydraulic loading-rack system was used to apply sustained compressive load to creep specimens.

A typical creep rack system consisted of a 12.5 mm inside diameter ram, three 305 mm x 305 mm x 25 mm mild steel plates, four 25 mm diameter steel bars of high yield steel with threaded ends, two pairs of 152 mm x 152 mm x 12.5 mm thick plates, a 25 mm steel rod and 16 hexagonal steel nuts.

The ram itself consisted of a 84 mm high, 25 mm thick, 215 mm normal inside diameter mild steel cylinder with a

Table 3 HSC strengths at given time

Age (days)	Ave. strength, MPa (psi) Mix (I)	Ave.strength, MPa (psi) Mix (II)
28	75 (10,738)	75 (10,763)
180	90 (13,149)	90 (13,088)
365	96 (13,894)	97 (14,080)

Table 1 Chemical and physical properties of the cement and fly ash

Type	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	Na_2O (%)	SO_3 (%)	Specific gravity	Blaine fineness
Cement	65.13	21.72	5.49	3.05	0.80	0.53	2.80	3.17	3241 cm^2/g
Fly ash	28.92	34.19	18.80	6.04	5.38	2.04	3.05	2.67	-

Table 2 Mix proportions

Mix	MSA (mm)	Cement (Kg/m^3)	Fly ash (Kg/m^3)	CA. (Kg/m^3)	Fine agg. (Kg/m^3)	Water (Kg/m^3)	W/(C+FA)	HRWR (g)
I	9.5	358	149	1.044	678	162	0.32	1260
II	25.4	357	148	1,170	612	144	0.29	1120

25 mm plate welded to the bottom and a close-fitting mild steel piston with neoprene 0-rings.

The cylinder and the piston were very carefully machined to close tolerances of about 0.1 mm. Pressure was applied to the cylinder through a hydraulic valve. A 100-ton "ENERPAC" or "POWER TEAM" hand-operated hydraulic pump and a control value to keep the desired loading levels were used in a typical loading rack system. When the cylinder specimens creep, the piston in the ram moves upward, and it would ordinarily cause a drop-off in the oil pressure and loss of applied axial loading.

The hydraulic loading rack system, however, seemed to maintain the oil pressure for approximately 2-3 days. After this interval, it was necessary to pump in a small amount of oil pressure (5-10% of applied pressure: higher loading level indicated more loss of pressure) to maintain a desired loading level. A total of four creep racks were erected in the environmentally controlled room. A typical diagrammatic sketch of creep test setup is shown in Fig. 1.

Two stress levels of 13.5 MPa (2,000 psi) and 20.0MPa (3,000 psi) were initially loaded on the creep specimens of Mix (I) and (II), respectively. Which are approximately 18% (N=0.18) and 27% (N=0.27) of the 28-day average compressive strength. A total of 12 creep readings were taken from each creep rack and were averaged to determine the creep strain using MPSG..

3. Experimental results and analyses

3.1 Drying shrinkage

The results of drying shrinkage test of two mixtures indicate that the amounts of drying shrinkage of HSC contained smaller maximum size of coarse aggregate (Mix I) exhibited greater than that of larger maximum size coarse aggregate (Mix II). The difference between two MSCA ranged from 30 to 35% during the whole test period for both 7 and 28-day cured HSC. Drying shrinkage of 28-day cured HSC showed 70-75% of the values of 7-days. In the present investigation, drying shrinkage almost stabilized after one year in the environmentally controlled room. The measured drying shrinkage of HSC developed rapidly at an early time (7-day cured HSC), where approximately 85% and 78% of the drying shrinkage at 365 days occurred in the first 100 days for Mix (I) and Mix (II), respectively. On the other hand, the measured drying shrinkages of 28-day cured HSC at the first 100 days were approximately 55% of the 365-day values for both Mix (I) and Mix (II). Based on the results, it may concluded that the drying shrinkage of HSC could significantly affect by the maximum size of coarse aggregate at early age of HSC, and became gradually decrease the effect. To predict drying shrinkage of 7-day cured HSC, a hyperbolic equation was adopted for the measured drying shrinkage data. A nonlinear curve fitting technique was used to develop prediction equation. The following two equations were proposed:

$$(\varepsilon_{sh})_t = \frac{t}{21+t}(428 \times 10^{-6} \text{ in/in}), \text{MSA=9.5 mm} \quad (5)$$

$$(\varepsilon_{sh})_t = \frac{t}{33+t}(342 \times 10^{-6} \text{ in/in}), \text{MSA=25.4 mm} \quad (6)$$

where, $(\varepsilon_{sh})_t$ = Predicted drying shrinkage of HSC at time t. t = time (day). The coefficient of determination, R^2, was obtained for each equation. It is a measure of the total variability of test data from a curve-fitting equation. The values of R^2 ranged from 0.99 to 0.98, respectively. This indicates that all drying shrinkage test data were closely related to the curves represented by equations (5) and (6). The prediction equations (Eqs. 5 and 6) developed in the present work may be compared with ACI 209 Code Model[6)] and equation found by Huo.[4)] These results are plotted alongside the experimentally obtained drying shrinkage data in Fig. 2.

As shown in Fig. 2, it seemed that the drying shrinkage values given by ACI 209 Code Model did not properly represent experimental drying shrinkages in this work. The difference ranged from 15% to 65% when compare to the average value of test results. On the other hand, the prediction equations and experimentally obtained drying shrinkage data found in the present work were showed a good agreement with the equation given by Huo.[4)]

To predict drying shrinkage of 28-day cured HSC, the following single equation, where an average value of experimental drying shrinkage for Mix (I) and (II) considered, was developed:

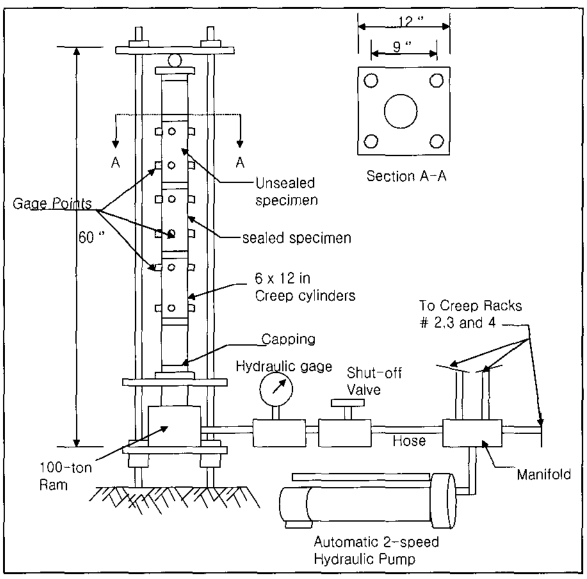

Fig. 1 Diagrammatic sketch of the creep test

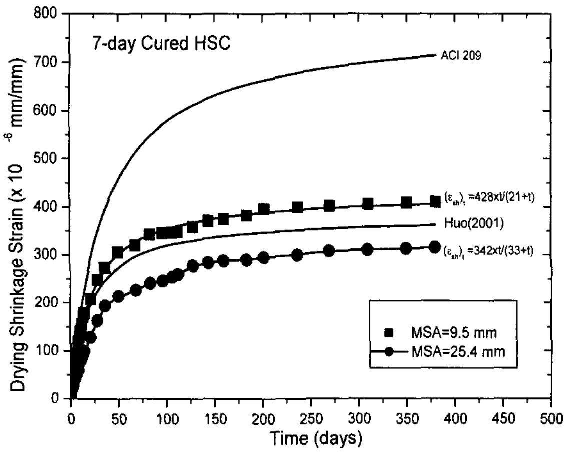

Fig. 2 Comparison for drying shrinkages

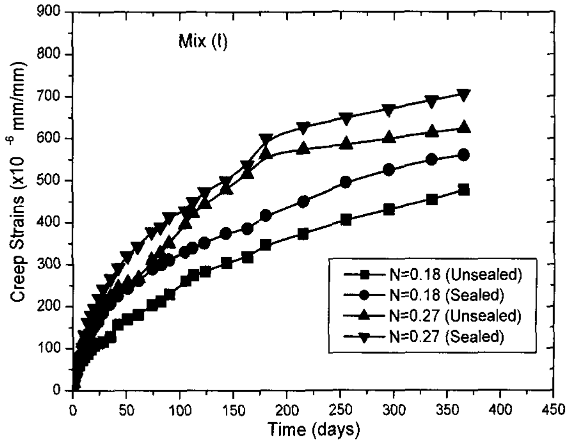

Fig. 4 Creep strains of mix (I)

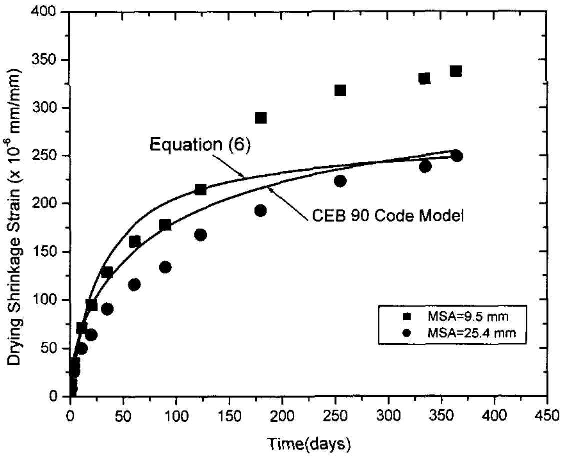

Fig. 3 Comparison of drying shrinkage on 28-day cured HSC

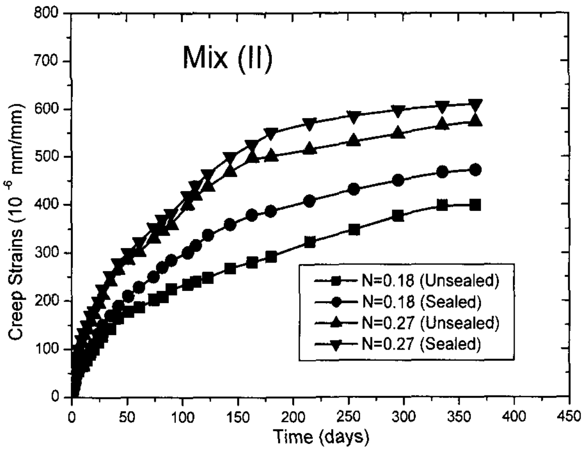

Fig. 5 Creep strains of mix (II)

$$(\varepsilon_{sh})_t = \frac{t}{29+t}(268 \times 10^{-6} \text{ in/in}), \text{MSA}=9.5, 25.4 \text{ mm} \quad (7)$$

Where, $(\varepsilon_{sh})_t$ = Predicted drying shrinkage of HSC at time t. t = time (day). The obtained value of R^2 was 0.68. This value is relatively low because an average value of two mixtures was used to derive equation. However, the prediction equation developed in the present work may be compared with existing drying shrinkage prediction model by Euro-International Concrete Committee -CEB 90 Code Model[12,13] with the 28-day compressive strength and relative humidity. These results are plotted alongside the experimentally obtained shrinkage data in Fig.3. The prediction equation given by Eq. (7) showed quite adequate for modeling the drying shrinkage of the high strength concrete. However, an additional investigation is needed to support or verify this equation.

3.2 Creep

The experimental results of creep tests of high strength concrete for Mix (I) and Mix (II) are plotted in Figs. 4 and 5, respectively. It is seen from Figs.4 and 5 that the larger the maximum size of aggregate showed the lower the creep strain on both sealed and unsealed cylinder specimens. Also creep strains of two mixtures showed a relatively faster development at early ages (90 days) than at late ages. Average creep strains at 90 days were approximately 55% of the 365-day creep strain. For N=0.18, the creep strain of Mix (I) was 20% higher than that of Mix (II). For N=0.27, the creep strain of Mix (I) was 10% higher than that of Mix (II) For a given mix and stress level, the creep strains of sealed specimens were 10% to 20% higher than that of unsealed specimens. This result was largely unexpected because normally the specimens subjected to air-dried curing (unsealed) exhibited higher creep strain than sealed specimens subjected to loading at early ages. From the one-year creep test of HSC in the present study, however, the creep strains of sealed specimens exhibited higher values. It appears that autogenous shrinkage was developed in the sealed specimens during test. Therefore, it assumes that the sustained creep strain of sealed specimens included both the creep deformation and autogenous shrinkage. The average creep coefficient, which is dividing the measured average creep strains by measured average elastic strains, was obtained. The average creep coefficients of specimens versus time are shown in Figs. 6 and 7, respectively. It can be seen from Figs. 6 and 7 that lower creep coefficients were observed from specimens under higher compressive load. A similar test result was reported in Huo's investigation.

A nonlinear regression technique was used to develop prediction equation of creep strain from the experimental results. The following two equations were proposed for prediction of creep coefficients of HSC for Mix (I) and (II):

$$\upsilon_t = \frac{t^{0.60}}{10 + t^{0.60}} \times 1.58, \text{ MSCA=9.5 mm} \quad (8)$$

$$\upsilon_t = \frac{t^{0.60}}{10 + t^{0.60}} \times 1.49, \text{ MSCA =25.4 mm} \quad (9)$$

Where, υ_t = Predicted creep coefficient of HSC at time t, and t= time (day). These two equations (Eqs.8 and 9) developed in the present work may be compared with equation of ACI 209 Code Model. These results are plotted alongside the experimentally determined creep coefficient

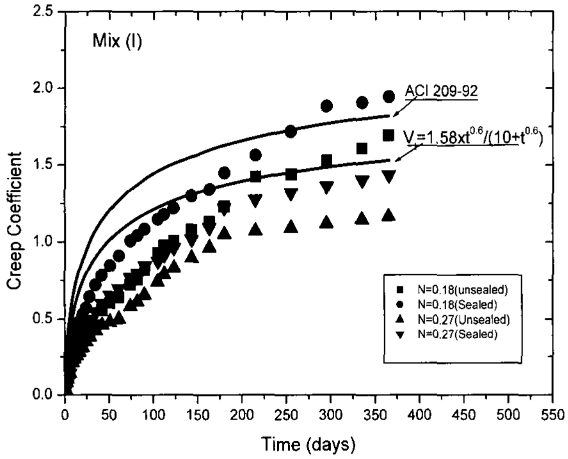

Fig. 6 Creep coefficients of mix (I)

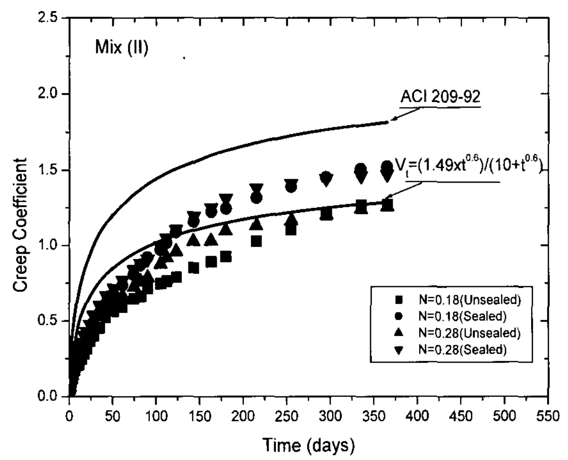

Fig. 7 Creep coefficients of mix (II)

data in Fig. 6 and 7, respectively. As shown in Figs. 6 and 7, creep coefficient from the developed equation (Eq. 8) for Mix (I) showed a better relationship than that of Mix (II) when compare to ACI 209 Code Model. The predicted creep coefficients in the present work ranged from 63% to 70% of that of ACI 209 Code Model. Based on the results from present work, the equation for creep strain in the ACI 209-92 Report can not accurately predict the creep coefficient of high strength concrete. A similar result was reported in Huo's investigation.

All creep racks were unloaded after 365 days. The recovering strains were recorded immediately. The average recorded elastic strain was 84% for Mix (I) and 79% for Mix (II), respectively. The average recorded creep strain under stress/strength level N=0.18 and 0.27 was 63.0 x 10^{-6} mm/mm. The creep recovery was 10% to 15% of the creep strains at 365 days. The total strain and recovery results are shown in Fig.8.

4. Summary and conclusions

Based on the experimental results of drying shrinkage and creep strain of high-strength concrete, the following conclusions are drawn:

1) The amount of drying shrinkage of HSC containing smaller maximum size of coarse aggregate (Mix I) exhibited greater than that of larger maximum size coarse aggregate (Mix II). The difference between two mixtures ranged from 30 to 35% for 7-day, and 20 to 25% for 28-day cured HSC.
2) Test results indicate that drying shrinkage of HSC developed rapidly at an early time, where approximately 85% and 78% of the drying shrinkage at 365 days occurred in the first 100 days for Mix (I) and Mix (II), respectively. It seems that drying shrinkage of HSC may significantly

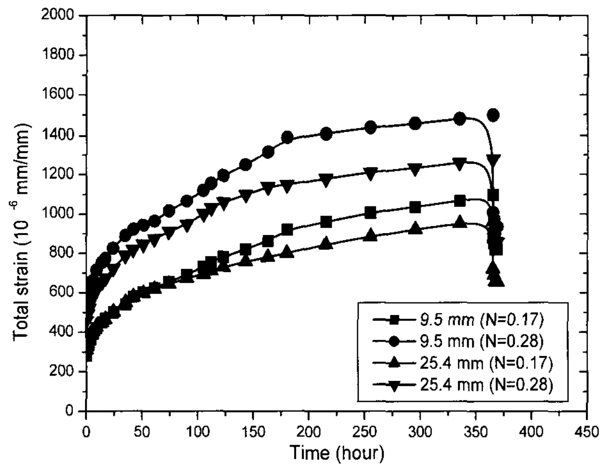

Fig.8 Total strain and recovery results

affect by the maximum size of aggregate at an early age of HSC, and become gradually decreased.

3) From the test results on drying shrinkage tests, prediction equations of ACI 209 Code Model may overestimated the actual shrinkage strains in 7-day cured HSC, but the developed equation given by Eq. (7) provided an adequate predictor of drying shrinkage strain for 28-day cured HSC when compared with CEB 90 Code Model.
4) Based on creep test results, prediction equations for creep coefficients of HSC were developed. The proposed equation for Mix (I) contained 9.5 mm MSCA showed a better relationship than that of Mix (II) when compare with ACI 209 Code Model.

References

1. Jianyong L. and Yan Y., "A Study on Creep and Drying Shrinkage of High Performance Concrete," *Cement and Concrete Research*, Vol.31, 2001, pp.1203~1206.
2. Persson B., "Correlating Laboratory and Field Tests of Creep in High-Performance Concrete," *Cement and Concrete Research*, Vol.31, 2001, pp.389~395.
3. Sapounttzakis E. J. and Katsikadelis J. T., "Creep and Shrinkage Effects on Reinforced Concrete Slab-and-Beam Structures," *J. of Engineering Mechanics*, Vol.128, No.6, 2002, pp.625~634.
4. Hou A. S., Al-Omaishi N., and Tadros M. K., "Creep, Shrinkage, and Modulus of Elasticity of High-Performance Concrete," *ACI Materials Journal*, Vol.98, No.6, 2001, pp. 440~449.
5. Khan A. A., Cook W. D., and Mitchell D., "Creep, Shrinkage, and Thermal Strains in Normal, Medium, and High-strength Concretes During Hydration," *ACI Materials Journal*, Vol.94, No.2, 1997, pp.156~163.
6. ACI Committee 209-92 Report, "*Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures (209R-92; Reapproved 1997)*," ACI, Detroit, 2002.
7. Mokhtarzadeh A. and French C., "Time-Dependent Properties of High-Strength Concrete with Consideration for Precast Applications," *ACI Materials Journal*, Vol.97, No.3, 2000, pp.263-271.
8. ASTM C 150, "*Standard Specification for Portland Cement*," Annual Book of ASTM Standards, 2002, Vol.4, No.1
9. ASTM C 494, "*Standard Specification for Chemical Admixture for Concrete*," Annual Book of ASTM Standards, Vol.4, No.2.
10. ASTM C 512, "*Standard Test Method for Creep of Concrete in Compression*," Annual Book of ASTM Standards, Vol.4, No.2, 2002.
11. ASTM C 618, "*Standard Specification for Coal Fly and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete*," Annual Book of ASTM Standards, Vol.4, No.2, 2002.
12. "*CEB-FIP Model Code 1990*," Design Code, Comité Euro-International du Béton, 1990.
13. Bhal, N.S. and Jain, J.P., "Effect of Age at the Time of Loading on Creep of Concrete," *Indian Concrete Journal*, Vol.69, No.9, 1995, pp.499~504.
14. Bhal, N.S. and Mittal, M.K., "Effect of Relative Humidity on Creep and Shrinkage of Concrete," *Indian Concrete Journal*, Vol.70, No.19, 1996, pp.21~27.