INFLUENCE OF ACTUAL ENVIRONMENTAL FACTORS ON SHRINKAGE BEHAVIOUR OF CONCRETE CONTAINING MINERAL COMPOUNDS

Naotunna C.N , Jayawardene E.L.A.I , Seneviratne D.A.M, Dr. Sudhira De Silva and Dr. Subashi De Silva

Abstract

This study was carried out to check whether the shrinkage can be reduced by using mineral admixtures and the shrinkage behavior of concrete containing mineral admixtures in actual environmental conditions. Since there are several environmental factors affecting on this shrinkage of concrete. Observation of shrinkage cracks in concrete structures is the most important aspect. Other than the observed data, it was necessary to get the predicted measurements of shrinkage from specific codes and models. But all these equations and models have been modeled in specific environmental situations. For most of them temperature and relative humidity values have taken as constants or under the control lab conditions. These codes or equations don't represent the exact situation for the structures in the local environmental conditions. Therefore in this study, one of the main aims is to find out, which model or code equation gives the most relevant relationship for the shrinkage strain in structures under actual environmental conditions.
Keywords: Shrinkage strain, silica fume, fly-ash, environmental conditions, Standard code predictions

1.0 INTRODUCTION

Study about Shrinkage behaviour in concrete is a common trend and it is the reason to find solutions for the common defect in any concrete structure. So, researchers are looking for solutions to shrinkage cracks and concrete deterioration by changing the properties of concrete. This research mainly focused in to the shrinkage behaviour in actual environment condition and how to minimise the problems by using mineral admixtures. It is a cost effective method and a way to improve concrete properties. There is no specific guide to predict shrinkage behaviour in actual environment conditions and shrinkage behaviour with mineral admixtures.

One of the causes that result in the early deterioration of reinforced concrete involves volume changes in concrete due to autogenous shrinkage and moisture loss. As concrete cures and dries, tensile stresses are created due to hydration and loss of moisture. The tensile stresses cause the concrete to shrink. Drying shrinkage is defined as the decrease in concrete volume with time due to moisture loss, whereas, autogenous shrinkage is defined as the reduction in volume of the concrete due to hydration of the cement. Drying shrinkage cracking is related not only to the amount of shrinkage, but also the modulus of elasticity, creep, and tensile strength of the concrete

Environmental factors which are effecting for the shrinkage strain in concrete are humidity, temperature and air velocity. Material effects are type and fineness of cement and additive amount of additives, type and gradation of coarse and fine aggregate. Additionally size and volume of the structure effects with the shrinkage strain in concrete. As it observed that several environmental factors are affecting on the shrinkage. In this research, it was investigated that the shrinkage behaviour in mineral added concrete at the actual environmental conditions.

Figure 1: Plastic Shrinkage cracks in concrete structures

Main objectives of this research are investigate the shrinkage strain development in concrete with mineral admixtures exposed to actual environmental conditions and identify the optimum utilization of mineral admixtures in concrete to control shrinkage cracking. Further study was carried out to identify the variation of actual values with Bazant B3 model, Gardner/Lokmen model, JSCE code, ACI code and CEB-FIP code for the shrinkage strain of concrete structures, exposed to both sun and rain[2].

2.0 METHODOLOGY

Shrinkage tests were performed for concrete specimens with Ordinary Portland Cement (OPC). Prismatic specimens with dimensions of 500x100x100 mm were prepared for the experiment. In order to cast the specimen, steel moulds were used. After 24 hrs, concrete specimens were removed from the moulds.

Two contact chips are pasted on a one side of a prism (about 20 hours after casting) as shown in Figure 2. During taking the measurements it is important to avoid the error due to temperature variation. Always the comparator was used to eliminate the errors. Other than the strain measurements, it is important to get the weight of the specimen, temperatures (indoor, outdoor and inside), relative humidity (from the wet and dry bulb temperature readings), and rainfall data.

Concrete specimens were not cured, and placed in appropriate environmental conditions as shown in Figures 3 to 5.

(a) Contact-chips placed Specimens

(b) Measuring Concrete Strain

Figure 2: Specimens for Concrete Strain Measurements

Silica fume and fly ash are used as the mineral admixtures. About 15% replacement of OPC by silica fume (by weight of cement) and 40% replacement of OPC by fly ash give the maximum compressive strength. Those percentages of mineral compounds are commonly used in the industry. Therefore above mentioned amounts of admixtures were used for the specimens in this research to examine the shrinkage behavior of concrete.

Table 1: Experimental Parameters

<table>
<tr><th>Specimen</th><th>Number of Specimens</th><th>Environmental Conditions</th></tr>
<tr><td>Control</td><td>3</td><td rowspan="3">1.Restrained both sun and rain.
2.Exposed only for sun radiation.
3.Exposed to both sun and rain.</td></tr>
<tr><td>Silica fume</td><td>3</td></tr>
<tr><td>Fly ash</td><td>3</td></tr>
</table>

Figure 3: Specimens are intersected to both sun and rain (kept in a non – air tight box)

Figure 4: Specimens are intersected to rain only (In this arrangement the prisms are kept as its any side does not block the evaporation.)

Figure 5: Specimens are exposed to both sun and rain.

3.0 RESULTS AND DISCUSSION

Figure 6 shows control specimens in different environmental conditions. The highest shrinkage strain shows for the case specimens exposed to, “only sun environmental condition”, relatively to two other environmental conditions. The main reason for that is; specimens in only sun condition do not contact with rain water. Only the evaporation of free water is occurred from the specimens. However, specimens exposed to “No sun and no rain” condition (Figure 3) show minimum shrinkage strain comparing to other environmental condition. This is due to the specimens do not contact with sun, the evaporation of free water content in specimens is very slow.

Figure 7 reveals that the both silica fume and fly ash specimens have very much lower shrinkage strain than control specimen. Specimens containing silica fume has the minimum shrinkage strain development in every environmental condition. This is due to the silica fume contains the finest particle size among other admixtures and cement. Therefore permeability of the concrete mix with silica fume get reduces.

For all three types of specimens (fly ash, silica fume, and control (OPC)) the highest shrinkage strain has occurred in “only sun” exposure condition. The main reason for that is specimens in only sun condition do not contact with rain water. Therefore it occurs due to the only the evaporation of free water from the specimen. Other than that, those specimens were kept under a shelter. Therefore the air flow close to the specimens is low. Because of that, the temperature inside the shelter would be higher than the outside temperature. The evaporation of free water in specimens would be relatively high.

“No sun and no rain” condition show minimum shrinkage strain comparing to other environmental conditions. When the specimens do not exposure to the sun, the evaporation of free water content in specimens would be very low.

Figure 8 represent the relationship between the experimental shrinkage strain values measured at the specimens exposed to actual environmental conditions with the predicted shrinkage strain according to the ACI and CEB-FIP cords. Figure 8 reveals that a drastic increase of shrinkage strain in the control specimen compared to the cord predicted shrinkage strain values.

4.0 CONCLUSIONS

This research has investigated the shrinkage strain development in concrete with mineral admixtures exposed to actual environmental conditions, which is actual and practical situation of concrete structures and identified that the optimum utilization of mineral admixtures in concrete for its shrinkage. The best shrinkage reducing admixture among these mineral admixtures is silica fume. Fly Ash also shows a relatively close reduction of shrinkage in concrete. Therefore considering the economical factors fly ash is much more suitable.

Further study was carried out to identify the variation of actual values with Bazant B3 model, Gardner/Lokmen model, JSCE code, ACI code and CEB-FIP code. It shows that the actual values of control specimens exposed to both sun and rain are rather away from the predicted values. Variation of data from each and every code and model has been analysed separately. From this comparison ACI code and Bazant B3 model residuals are much smaller than the other prediction models. ACI code model is the most acceptable than the other models.

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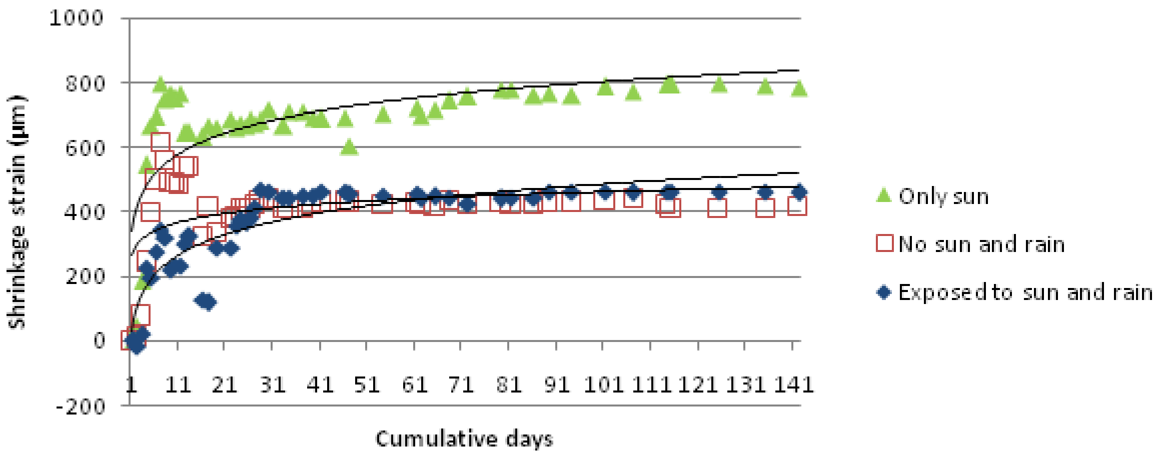

Figure 6: shrinkage strain variation with cumulative days (control specimen)

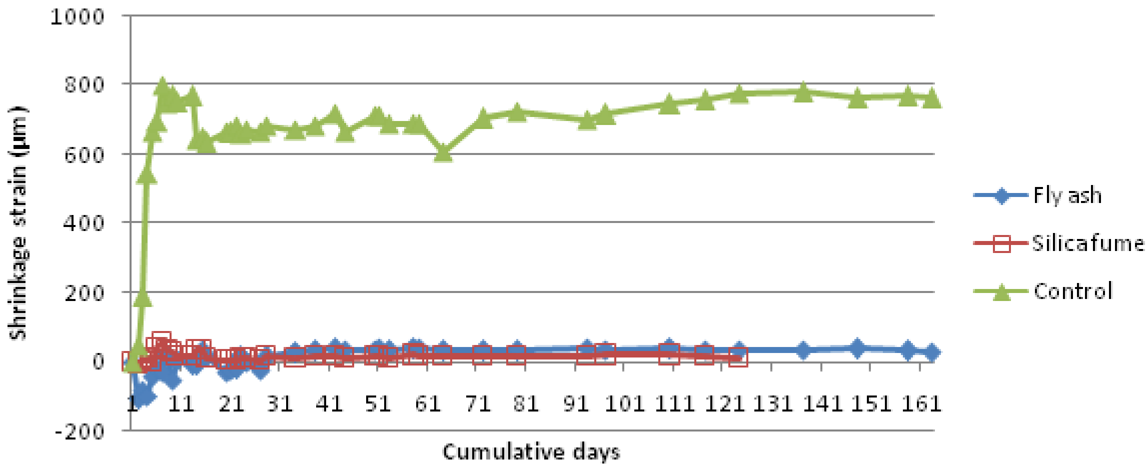

Figure 7: Shrinkage strain variation with cumulative days (Exposed to both sun and rain)

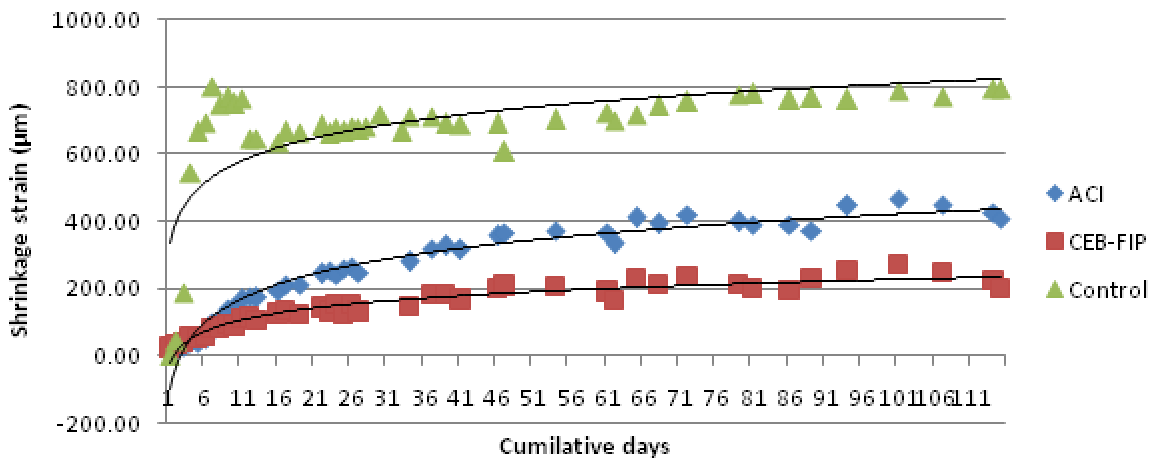

Figure 8: Comparison of codes shrinkage strain and experimental strain variation with cumulative days (Exposed to both sun and rain)

APPENDIX 1

SHRINKAGE STRAIN PREDICTION MODELS

ACI committee 209 (1982)

This code equation is applicable for the light weight concrete under the standard conditions according to ACI 209 code.

Shrinkage after 7 days for moist cured concrete

$$\varepsilon sh(t) = (t / 35+t)\ \varepsilon sh'u \quad (1\text{-}1)$$

shrinkage after 1 – 3 days for steam cured concrete

$$\varepsilon sh(t) = (t / 55+t)\ \varepsilon sh'u \quad (1\text{-}2)$$

$$\varepsilon sh'u = 780\ \gamma_{sh} \times 10^{-6} \quad (1\text{-}3)$$

$$\gamma_{sh} = \gamma_h \cdot \gamma_l \cdot \gamma_{vs} \cdot \gamma_s \cdot \gamma_\psi \cdot \gamma_c \cdot \gamma_\alpha \quad (1\text{-}4)$$

$$\gamma_h = 1.4 - 0.01\ h, \quad \text{for } 40 <= h <= 80$$

$$3.0 - 0.03\ h, \quad \text{for } 80 <= h <= 100 \quad (1\text{-}5)$$

During the first year after loading

$$\gamma_l = 1.23 - 0.00015\ l \quad (1\text{-}6)$$

For ultimate values

$$\gamma_l = 1.17 - 0.00114\ l \quad (1\text{-}7)$$

$$\gamma_{vs} = 1.2 \exp(-0.00472\ .\ V/S) \quad (1\text{-}8)$$

$$\gamma_s = 0.89 + 0.00161\ .\ s \quad (1\text{-}9)$$

$$\gamma_\psi = 0.30 + 0.014\ .\ \psi \quad \text{for } \psi <= 50 \quad (1\text{-}10)$$

$$= 0.90 + 0.002\ .\ \psi \quad \text{for } \psi > 50$$

$$\gamma_c = 0.75 + 0.00061\ .\ C \quad (1\text{-}11)$$

$$\gamma_\alpha = 0.95 + 0.008\ .\ \alpha \quad (1\text{-}12)$$

$\varepsilon sh'u$: ultimate shrinkage strain ($\times 10^{-6}$),

h : ambient relative humidity (%),

l : average thickness of the member section (mm),

V/S : volume surface ratio (mm),

S : observed slump (m),

Ψ : the ratio of fine aggregate to total aggregate by weight (%),

C : unit cement content (kg/m^3),

α : the air content (%)

CEB-FIP model code 1990
Shrinkage strain is expressed as;

$$\varepsilon_{cs}(t,\ t_s) \ = \ \varepsilon_{cso}\beta_s(t \ - \ t_s) \qquad (2\text{-}1)$$

ε_{cso} : notional shrinkage coefficient

β_s : coefficient to describe the development of shrinkage with time

t : age of concrete (days)

t_s : age of concrete (days) at the beginning of shrinkage

Notional shrinkage is obtained from

$$\varepsilon_{cso} \ = \ \varepsilon_s(f_{cm})\beta_{RH} \qquad (2\text{-}2)$$

$$\varepsilon_s(f_{cm}) \ = \ [160 \ + \ 10\beta_{sc}(9 \ - \ f_{cm}/f_{cmo})] \ \times \ 10^{-6} \qquad (2\text{-}3)$$

Where,

f_{cm} : Mean compressive strength of concrete at the age of 28 days (MPa)
= 10 MPa

βsc : Coefficient which depends on the type of cement.
βsc = 4 for slowly hardening cements SL, βsc = 5 for normal or rapid hardening cements N and R and βsc = 8 for rapid hardening high strength cements

$$\beta_{RH} \ = \ -1.55\beta_{sRH} \text{ for } 40\% \leqslant RH < 99\%$$
$$\beta_{RH} \ = \ +0.25 \qquad \text{for } RH \geqslant 99\% \qquad (2\text{-}4)$$

Where,

$$\beta_{sRH} \ = \ 1 - \left(\frac{RH}{RH_o}\right)^3 \qquad (2\text{-}5)$$

RH : Relative humidity of the ambient atmosphere (%) ,

Rh_o = 100%

The development of shrinkage with time is given by

$$\beta_s(t \ - \ t_s) \ = \ \left[\frac{(t \ - \ t_s)/t_1}{350(h/h_o)^2 \ + \ (t \ - \ t_s)/t_1}\right]^{0.5} \qquad (2\text{-}6)$$

Where ,

h	$= 2A_c/u$	(2-7)
h	: notational size of member (mm)	
A_c	: cross section	
u	: perimeter of the member in contact with the atmosphere	
h_o	$= 100$ mm	(2-8)
t_1	$= 1$ day	(2-9)

JSCE code 2002 for normal and high strength concrete (2002)

JSCE code specified shrinkage strain calculation into two methods. One is used for normal concrete with a compressive strength of 55 N/mm^2 (or 70 N/mm^2 when w/c ratio is reduced to increase strength) and the other for high strength concrete with a compressive strength exceeding 55 N/mm^2 up to 120 N/mm^2. Following equations are used in cases, where drying begins between the age of 3 and 90 days. It is applicable to concrete having w/c ratio between 0.4 and 0.65. The applicable temperature is ranging from 0^{o}C to 40^{o}C. According to the JSCE code, the same prediction model may be used for the shrinkage strain of lightweight aggregate concrete.

For normal concrete

$$\varepsilon'_{cs}(t,t_o) = [\, 1- \exp\{ - 0.108(t-t_o)^{0.56}\}]\, \varepsilon'sh \qquad (3\text{-}1)$$

$$\varepsilon'_{sh} = -50 + 78\, [1 - \exp(RH/100)\,] + 38\ln W - 5[\ln((V/S)/10)]^2 \qquad (3\text{-}2)$$

where,

ε'_{sh} : final value of shrinkage strain [x 10^{-5}]

ε'_{cs} : shrinkage strain between ages t_o and t [x 10^{-5}]

RH : ambient relative humidity [%]
(45% <= RH <= 80%)

W : unit content of water [kg/m^3]
(130 kg/m^3 <= W <= 230 kg/m^3)

V : volume [mm^3]

S : surface area in contact with air [mm^2]

V/S : volume-surface ratio [mm] (100mm <= V/S <=300mm)

t_o and t temperature adjusted age [days] of concrete at the beginning of drying and during drying, where the value corrected by below Equation should be used.

$t_o, t = \sum_{i=1}^{n} \Delta ti \cdot \exp[13.65 - (\frac{4000}{273 + T\frac{\Delta ti}{To}})]$ (3-3)

Δti: : number of days when the temperature is T(°C),

T(Δti) : the temperature during the time period Δti [°C], and T_o: 1°C

Bazant B3 Model (Bazant, 1995)

$$\varepsilon_{sh}(t, t_o) = -\varepsilon_{sh\infty} K_h S(t) \quad (4\text{-}1)$$

$$\varepsilon_{sh\infty} = -\alpha_1\alpha_2\left(26(w)^{2.1}(f_c')^{-0.28} + 270\right) * 10^{-6} \quad (4\text{-}2)$$

$$K_h = 1 - h^3 \quad (4\text{-}3)$$

$$S(t) = \tanh\sqrt{\frac{t - t_o}{T_{sh}}} \quad (4\text{-}4)$$

ε_{sh}(t,to) : shrinkage strain (in./in.)

$\varepsilon_{sh}(\infty)$: ultimate shrinkage strain (in./in.)

α_1 and α_2 : equals to 1.0

w : water content of concrete (lb/ft^3)

Kh : cross-section shape factor

h : relative humidity (%)

t : age of concrete (days)

t_o : age of concrete at beginning of shrinkage

S(t) : time function for shrinkage

Gardner/Lockman Model (Gardner, 1998)

$$\varepsilon_{sh} = \varepsilon_{shu}\beta(h)\beta(t) \quad (5\text{-}1)$$

$$\varepsilon_{shu} = 1000 * K * \left(\frac{4350}{f_{cm28}'}\right)^{1/2} * 10^{-6} \quad (5\text{-}2)$$

$$\beta(h) = 1 - 1.18h^4$$

$$\beta(t) = \left(\frac{(t - t_c)}{t - t_c + 97(V/S)^{1/2}}\right) * 10^{-6} \quad (5\text{-}3)$$

ε_{sh} : shrinkage strain (in./in.)

ε_{shu} : ultimate shrinkage strain (in./in.)

b(h) : correction term for effect of humidity on shrinkage; h: humidity

b(t) : correction term for effect of time on shrinkage tc : age drying commenced (days) and t : age of concrete (days)

K : correction term for effect of cement type