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Evaluation of Autogenous Shrinkage of High-Performance Concrete

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ABSTRACT

Recent trends in concrete technology have been towards so-called high- performance concrete with a low water-cement ratio. However, these high performance concretes have some problems. One of the problems is early-age cracking due to autogenous shrinkage. This study presents the results of an experimental investigation carried out to evaluate the autogenous shrinkage of High-Strength Concrete. According to this, effects of water/binder ratio, cement content, fine to coarse aggregate ratio and silica fume percentage were evaluated. From the results of the above investigation the autogenous shrinkage strain of high strength concrete increases with w/b ratio reduction and silica fume percentage increased. The results show that the effect of varying cement content had only a limited effect on the autogenous shrinkage. The autogenous shrinkage strain of concrete increases slightly with increase the fine to coarse aggregate ratio. Following this the autogenous shrinkage strain prediction models are evaluated for their accuracy.

Keywords: High-Strength Concrete, Autogenous Shrinkage, Silica Fume, Strain Prediction Model

INTRODUCTION

Today high-strength concrete widely use throughout the world and to produce them it is necessary to reduce the water/binder ratio and increase the binder content. Superplasticizers are used in these concretes to achieve the required workability. Moreover different kinds of cement replacement materials are usually added to them because a low porosity and permeability are desirable (Feylessoufi, 2001). Silica fume is the one of the most popular pozzolanes, whose addition to concrete mixtures results in lower porosity, permeability and bleeding because their oxides ($SiO2$) react with and consume calcium hydroxides, which were produced by the hydration of ordinary Portland cement.
Shrinkage is the decrease of concrete volume with time. This decrease is due to change in moisture content of the concrete and physio-chemical changes, which occur without stress attributable to actions external to the concrete (Persson, 1998).When no moisture transfer is permitted with the environment , this volume change is called Autogenous shrinkage and is attributed to self-desiccation due to the hydration of concrete. Autogenous shrinkage does not usually appear in conventional, normal strength concrete but in high-performance concrete such as high- strength and self-compacting concrete with a low water-cement

ratio(w/c), not negligible(Mazloom, 2004). Indeed, several researchers reported that high-strength concrete might crack as a consequence of restrained autogenous shrinkage deformations (Cusson, 2007).
In this study, the autogenous shrinkage strain in high-strength concrete was investigated. Effects of water-binder ratio, cement content, silica fume percentage and fine to coarse aggregate ratio, on the autogenous shrinkage behavior were discussed.

MATERIALS AND METHOD

The cement used was of Portland type 1 and the maximum size of the aggregate was 19 mm. A naphthalene formaldehyde superplasticizer(sp) was used to maintain the workability of the mixtures. Detail of the mix proportions of the concretes are given in table 1. Eleven different concrete mixes were used to cast the specimens.

Table 1. Details of Mix Proportions

Mix	W/C	C(kg/m3)	S(kg/m3)	G(kg/m3)	SF(%)	SP(%)	Slump(cm)
1	0.35	450	900	850	10	2	8
2	0.4	450	900	850	10	2	12
3	0.45	450	1700	0	10	2	8
4	0.3	450	900	850	10	2	4
5	0.35	500	900	850	0	2	8
6	0.35	400	900	850	20	2	12
7	0.35	540	900	850	10	2	12
8	0.35	315	900	850	10	2	8
9	0.35	450	700	1050	10	2	12
10	0.35	450	1050	700	10	2	15

C:cement, S:sand, G:gravel, SF:silica fume, SP:superplasticizer.

All mixing was carried out in a tilting drum mixer of 0.1 m3 capacity. The fine and coarse aggregate together with cement were mixed dry for 1.5 min. The silica fume slurry was then added. At last the water and superplasticizer were added gradually while the mixer was in motion .The total mixing time was approximately 4 min for the mixes. For each mix, the 100 mm cubes for compressive strength specimens were made.
Shrinkage of concrete was measured with the help of shrinkage Apparatus as shown in figure 1.This apparatus measured the variations of the vertical angle in the determinate times. Then the shrinkage deformations were obtained by triangles equations.
Concrete specimens of 80x80mm in cross section and 280 mm length were cast with various concrete mixes. All the moulds were filled in two layers with each layer being compacted by means of a vibrating table for approximately 1 min. The compacted specimens were covered with wet burlap to prevent water loss during the first 24 h after casting .The shrinkage specimens were demoulded on the following day and immediately covered with curing material to prevent water loss during the test. Hence the measured deformations were the autogenous shrinkage strain. The 100 mm cubes specimens after demoulding, to determine the 7 and 28 day compressive strengths were placed in a water tank at 20 ±2 ºc.

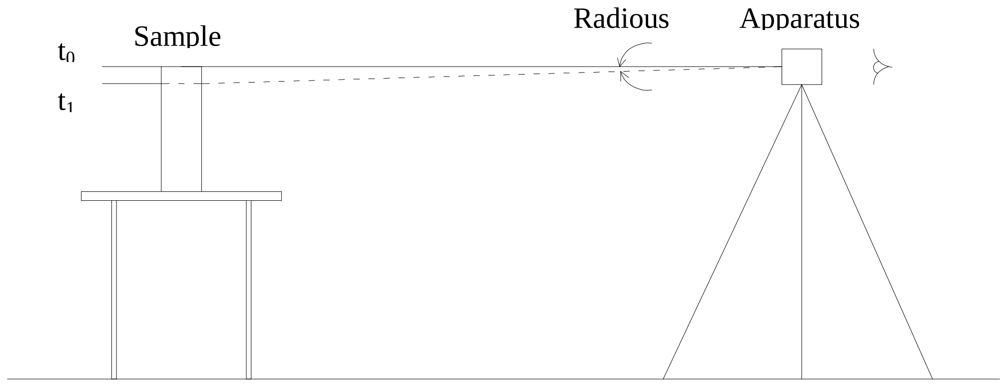

Fig 1. The Shrinkage Measurement Apparatus

RESULTS AND DISCUSSION

1. Compressive Strength

For concrete stored in water, the development of compressive strength with age is shown in Table 2. It can be seen that the compressive strength development of concrete mixture containing 10% silica fume was higher than mixtures containing 0 and 20% silica fume .The mixture with s/g ratio of 2 to 3, had lower f'c than ratio of 1 to 1 and 3 to 2.
However the compressive strength concrete mixture number 4 that had lowest w/c ratio was higher than other. From this it can be concluded that w/c ratio have most effect on the compressive strength of concrete.

Table 2. Compressive Strength of Concrete Mixes (MPa)

Mix		1	2	3	4	5	6	7	8	9	10
f'c	7 day	42	38	30	43	42	36	37	36.5	37	41
	28 day	70	65	51	76	63	65	72	58	52	73

2. Autogenous Shrinkage

The results of the autogenous shrinkage strains of various concrete mixes are given in tables 3 to 6 and figures 2 to 6 respectively. These results are discussed in detail as under:

Table 3. Effect of the W/C Ratio on the Autogenous Shrinkage Strain

Mix	W/C	Strain(μ)			
		3 day	7 day	14 day	28 day
1	0.35	60	145	165	165
2	0.40	60	85	125	125
4	0.30	105	230	250	250

Table 4. Effect of the SF percentage on the autogenous shrinkage strain

Mix	SF %	Strain(μ)			
		3 day	7 day	14 day	28 day
1	10.0	60	145	165	165
5	0.0	60	105	125	145
6	20.0	210	250	270	270

Table 5. Effect of the cement volume on the autogenous shrinkage strain

Mix	C kg/m3	Strain(μ)			
		3 day	7 day	14 day	28 day
1	450	60	145	165	165
7	540	40	165	190	190
8	315	60	125	145	145

Table 6. Effect of the S/G ratio on the autogenous shrinkage strain

Mix	S/G	Strain(μ)			
		3 day	7 day	14 day	28 day
1	1/1	60	145	165	165
9	2/3	60	125	145	165
10	3/2	40	125	190	210

The shrinkage strains of various concrete mixes with different levels of w/b ratio are shown in table 3 and figure 2.From the test results it is concluded that the autogenous shrinkage strain of mixes increases (32 to 100%) with decrease the w/b ratio. To hydration the cement, need to water in the cement paste. Decrease the w/b cause to increase the autogenous shrinkage. This result was shown in the figure 2 clearly.

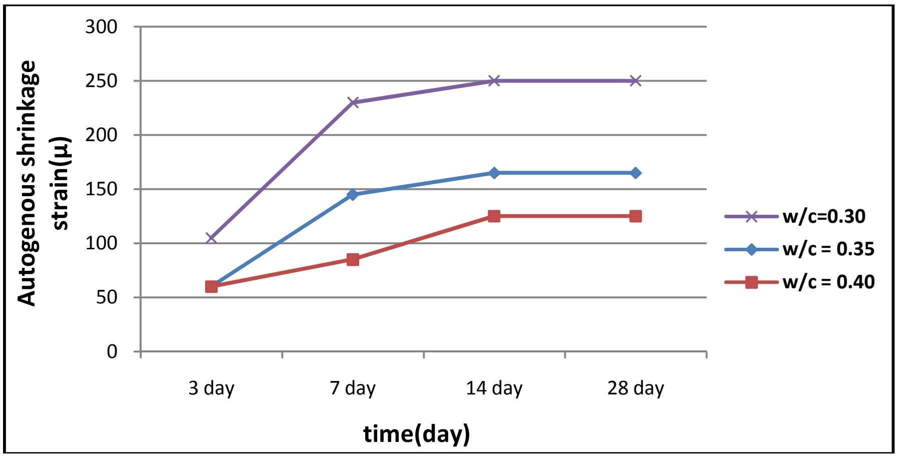

Fig 2. Variation of Autogenous Shrinkage Strain of H.S.C with W/C Ratio

Effect of the varying the cement content on the autogenous shrinkage are shown in table 5 and figure 3 .This results indicate that high-strength concrete containing higher cement content shows large autogenous shrinkage strain because increases the paste volume. The shrinkage deformations occur in the paste. Then increases the paste volume cause the shrinkage strain to increase.

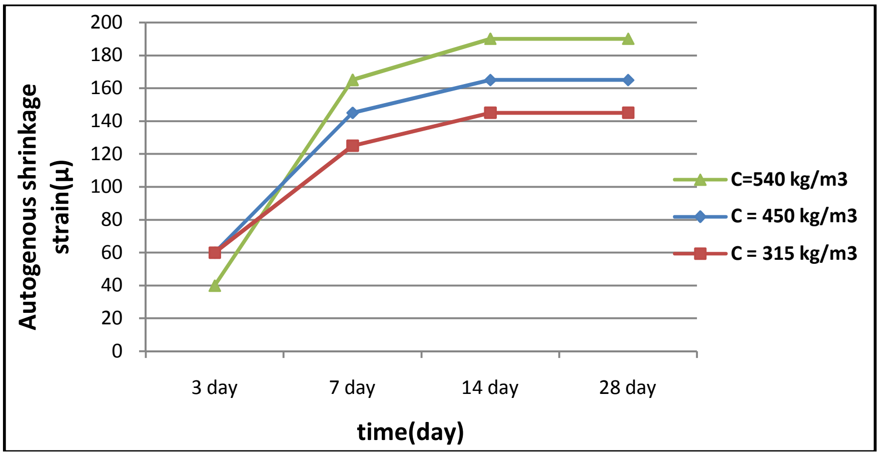

Fig 3. Variation of autogenous shrinkage strain of H.S.C with cement amount

Fig 4 shows that adding 10-20 % of silica fume to the mix increase the autogenous shrinkage strains of high-strength concrete with time. This may be due to the increase pastes that cause large shrinkage by partially replacing cement with silica fume that have a higher specific surface area.

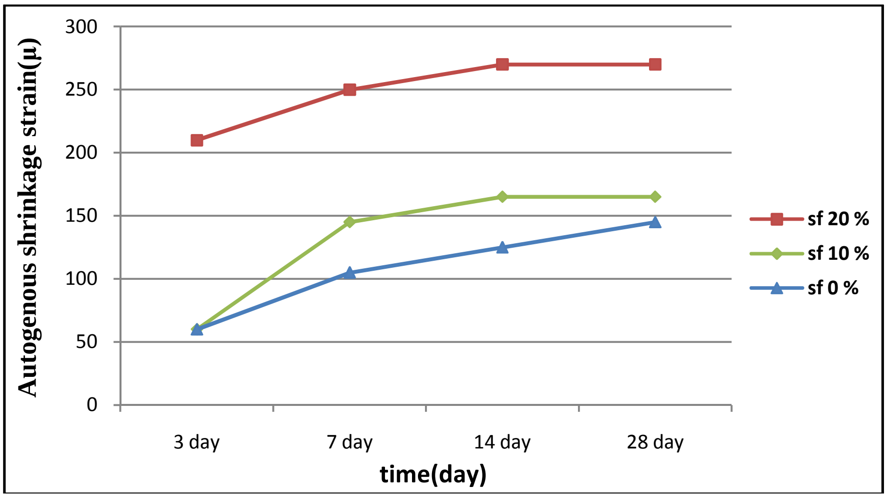

Fig 4. Variation of autogenous shrinkage strain of H.S.C with SF ratio

The results shown in figure 5 show that the effect of fine to coarse aggregate ratio on the autogenous shrinkage of high-strength concrete. The autogenous shrinkage strain increases slightly with increasing this ratio.

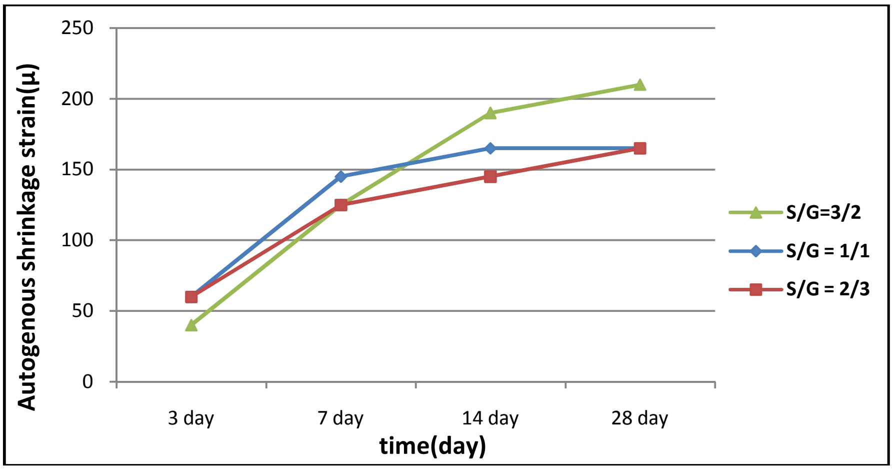

Fig 5. Variation of autogenous shrinkage strain of H.S.C with S/G ratio

Autogenous shrinkage of concrete occurs as a result of chemical reactions during the hydration of cementitious materials and is not related to moisture movement from concrete to the atmosphere. This means large sizes of structural elements or painting the surface of them do not reduce this kind of shrinkage. Consequently, any restraint to the deformation can induce tension stress and cracking in concrete members. For instance, the reinforcement bars of structural elements or stiff structural supports or even adjacent structural members can resist autogenous shrinkage and cause micro cracks (Mazloom, 2004). Cracking can increase the permeability of concrete and therefore, especially in severe environments, its durability decreases. It should be mentioned that Loukili et al. believe this shrinkage in very high-strength concrete stops after 10 days (loukili, 1999). From this, in this study the autogenous shrinkage strain measured for 28 days from casting.
This investigation shows one of the ways to minimize autogenous shrinkage and also the cracking probability of high-strength concrete is to add not more than 10% silica fume to the mix. Some other researchers believe that fiber reinforced concrete is very useful in this field (Tazawa, 1997). Of course, new recommendations of RILEM should be considered in steel fibers (Gupta, 2009). Some investigators recommend utilizing expansive admixtures to compensate autogenous shrinkage (Wu, 1996). Another method is to use lightweight aggregates in concrete [8] because their water adsorption is high and the internal water lost by self-desiccation of cement paste is immediately replaced by moisture from the lightweight aggregate. Also shrinkage-reducing admixtures are useful to decrease autogenous shrinkage (Tazawa, 1997). These chemical materials reduce the surface tension of capillary water (Mazloom, 2004). Montani has suggested applying expansive and shrinkage-reducing admixtures together as a method to control concrete shrinkage.

3. Autogenous Shrinkage Strain Prediction Models

Four autogenous shrinkage prediction models are presented in this study. The discussion is concentrated on evaluating the accuracy of these models. This is accomplished by comparing the theoretical results that obtained by these models and experimental data. These four models are the CEB FIP MC 90 Model, the JSCE 2002 Model, the Euro Code 2001, and Doctor Mazloom Model.

3.1. The CEB FIP MC 90 Model

The CEB FIP MC 90 Model is recommended by CEB-FIP Model Code 1990(Euro-International **Concrete** Committee and International Federation for Prestressing). Earlier models include: CEB-FIP-1970 and CEB-FIP-1978 Models.
In this model, the following factors are considered for prediction of autogenous shrinkage strain: cement type, concrete age and compressive strength of concrete.

$$\varepsilon_{cas} = \varepsilon_{caso} (f_{cm}) \cdot \beta_{as} (t) \tag{1}$$

This model can be applied for concretes with average 28-day compressive strength ranging from 20 MPa to 90 MPa.

3.2. The JSCE 2002 Model

The JSCE 2002 Model is recommended by the Japan Society of Civil Engineers. The autogenous shrinkage strains are expressed as functions of time:

$$\varepsilon_c (t) = \gamma . \varepsilon_{co} . \beta (t) \tag{2}$$

In this model, the following factors are considered for prediction of autogenous shrinkage strain: cement type, concrete age and water to cement ratio of concrete.

3.3. The Euro Code 2001 Model

The Euro Code 2001 Model is recommended by the Europe Concrete Institute. The required parameters are: cement type, concrete age and compressive strength of concrete.

$$\varepsilon_{cs} = \beta_{cc}(t) \cdot \varepsilon_{cs\infty} \tag{3}$$

3.4. The Doctor Mazloom Model

The Doctor Mazloom Model is developed by Doctor M. Mazloom, A.A. Ramezanianpour and J.J. Brooks in 2004.

$$\varepsilon_{sh} (t) = \frac{t}{0.3sf+12.6+t} \times 516\ y_s \tag{4}$$

In this model, the following factors are considered for prediction of autogenous shrinkage strain: concrete age and silica fume percentage.

4. Study Results

The results for autogenous shrinkage strain are presented in the following figures. The shrinkage strain values were calculated by the four analyzed models. Those values were compared against the experimental data.

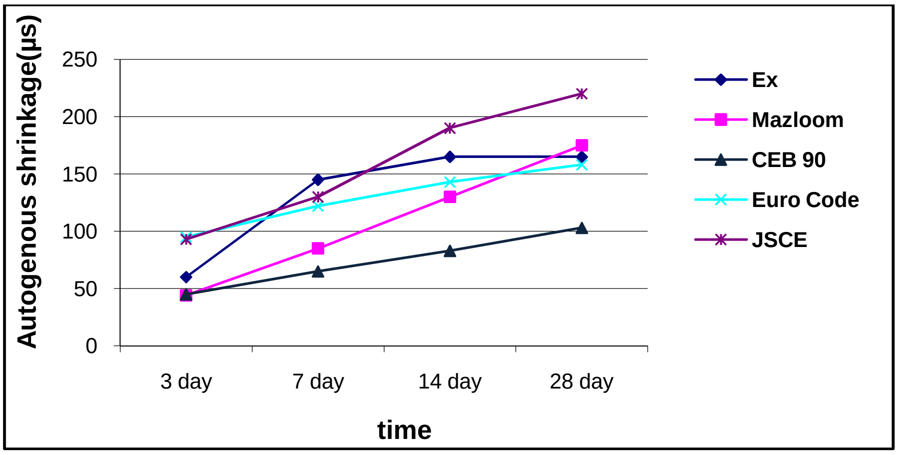

Fig 6. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 1

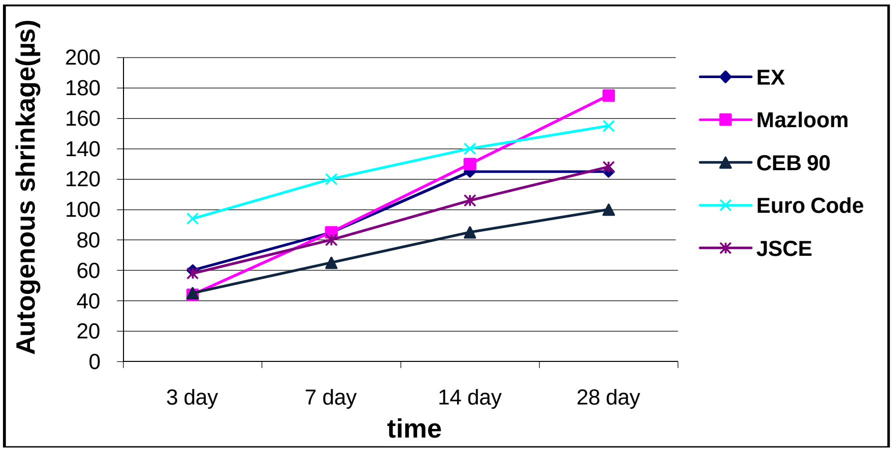

Fig 7. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 2

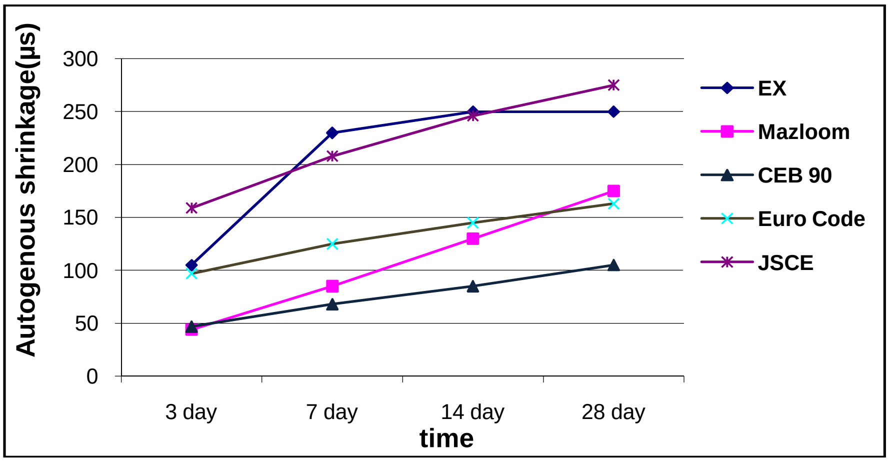

Fig 8. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 4

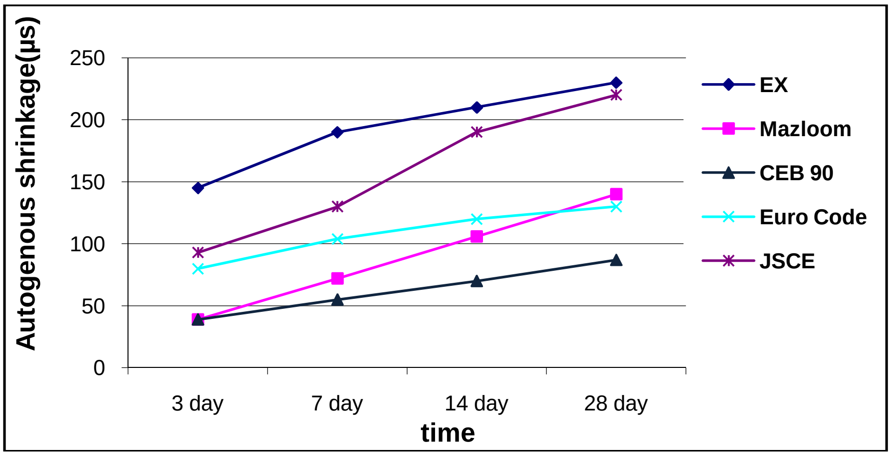

Fig 9. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 5

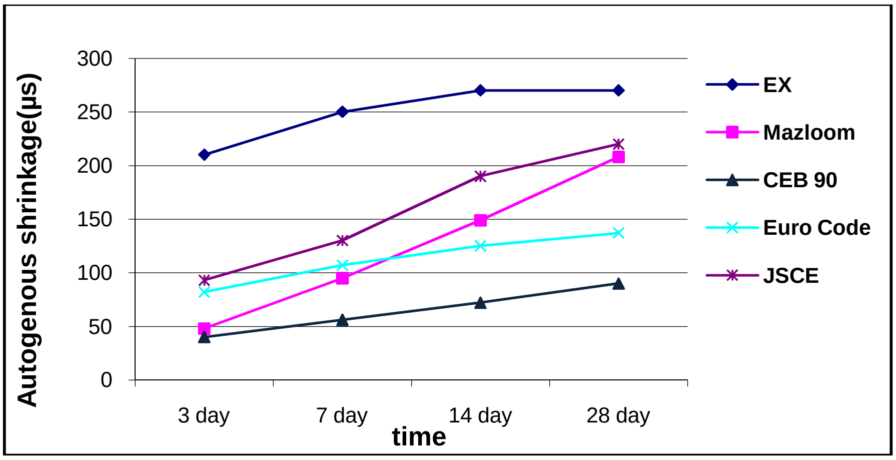

Fig 10. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 6

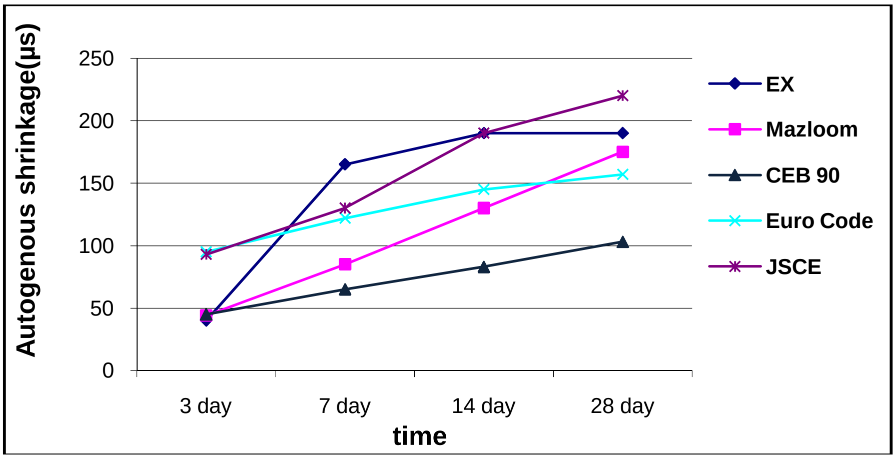

Fig 11. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 7

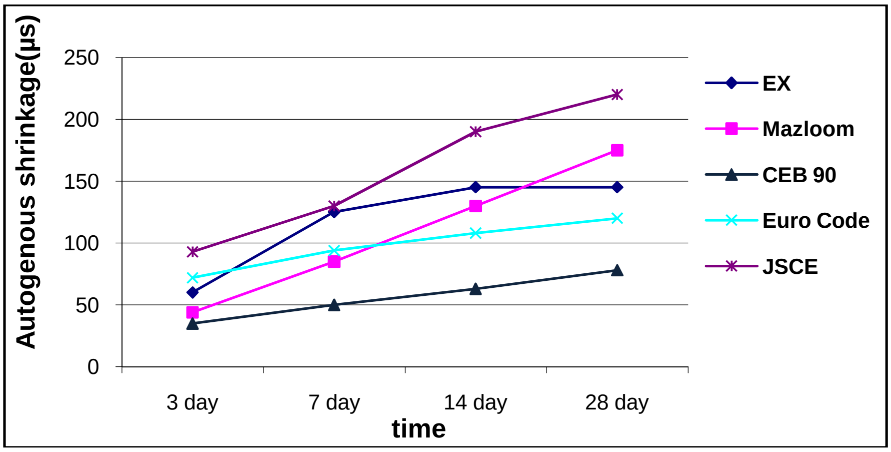

Fig 12. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 8

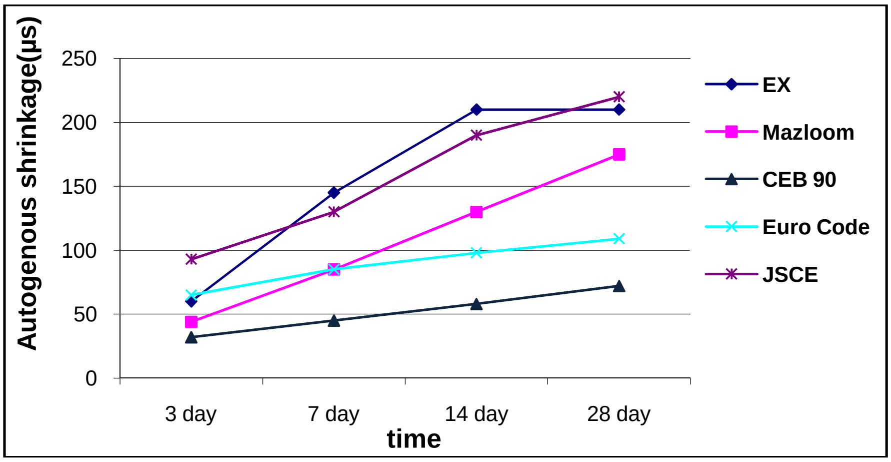

Fig 13. The Autogenous Shrinkage Strain Residuals for Four Models Comparing the Experimental Data for Mix Number 9

Four different autogenous shrinkage models are compared with the experimental data to determine the level of their accuracy. The studied models are the CEB FIP MC 90 Model, the JSCE 2002 Model, the Euro Code 2001 Model, and the Doctor Mazloom Model. From the figures of 5 to13 this can be concluded that the JSCE 2002 Model performed best for predicting autogenous shrinkage strain.

CONCLUSIONS:

The following conclusions were drawn of this study on autogenous shrinkage of HPC:

1- The autogenous shrinkage strain of H.P.C increases extremely when the W/C ratio was decreased.
2- The autogenous shrinkage strains of H.P.C with replacement of 10-20 % cement by silica fume at different ages are more than the autogenous shrinkage strain of H.P.C without silica fume.
3- The autogenous shrinkage strain of H.P.C increases slightly with increase the cement content and the fine to coarse aggregate ratio.

4- From the four models that presented, the JSCE 2002 Model had the best accuracy.

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