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Evaluation of Autogenous Shrinkage in High-Performance Concrete

J. Ahmadi[1,*], R. Naghdi[2]

[1]*Assistant Professor at University of Zanjan, Zanjan, Iran*

[2]*Faculty of Engineering, University of Zanjan, Zanjan, Iran*

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Abstract

Recent tendencies in concrete technology have been towards to high- performance concrete with a low water-cement ratio. However, 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 content were evaluated. From the results of this investigation, it can be concluded that the autogenous shrinkage strain of high strength concrete increases with reduction of w/b ratio. The results show also that the variation of cement content and fine to coarse aggregate ratio had only a limited effect on the autogenous shrinkage.

Keywords: Autogenous Shrinkage, High-Performance Concrete, Silica Fume, High-Strength Concrete.

1. Introduction

High-strength concrete as a high-performance concrete is widely used throughout the world. for production of high-strength concrete it is necessary to reduce the water/binder ratio and increase the binder content. Super plasticizers are used in these concretes to achieve the required workability. Moreover different kinds of cement replacement materials are usually added to this kind of concrete to achieve the low porosity and permeability of concrete [1]. Silica fume is the one of the most popular pozzolans. The addition of silica fume to concrete mixtures reduces the porosity, permeability and bleeding capability of concrete because of the SiO_2 compounds reactions and the calcium hydroxides consume.

Shrinkage is defined as a reduction of concrete volume in over the time. This decrease is due to the concrete moisture changes, which occurs without any external applied stress [2].When there is no moisture transfer into the environment, this volume change is called autogenous shrinkage and is attributed to self-desiccation of concrete due to the hydration propagation.

Autogenous shrinkage does not usually appear in conventional and normal strength concrete. While in high-performance concrete such as high- strength and self-compacting concrete with a low water-cement ratio (w/c), this phenomenon is not negligible [5]. Indeed, several researchers reported that high-strength concrete may crack as a consequence of restrained autogenous shrinkage [7].

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 that the sizes of structural elements or covering the surface of them do not reduce this kind of shrinkage. Consequently, any restraint against the deformation can induce tensile stress and cracking in concrete members. For instance, the reinforcement bars of structural elements [4] or stiff structural supports or even adjacent structural members can resist against autogenous shrinkage and cause micro cracks. Cracking can increase the permeability of concrete and therefore, especially in severe environments, its durability decreases. Lura et al. [4] believe this shrinkage in very high-strength concrete stops after 10 days.

Some other researchers believe that fiber reinforced concrete is very useful in this field [4-7]. Of course, new recommendations of RILEM should be considered in steel fibers. Some investigators recommend the utilizing expansive admixtures to compensate autogenous shrinkage [4,7]. The other researcher proposes using of lightweight aggregates in concrete for internal curing of concrete [8]. Also shrinkage-reducing admixtures are useful to control autogenous shrinkage [5]. These chemical materials reduce the surface tension of capillary water. Tazawa [8] has suggested applying expansive and shrinkage-reducing admixtures as a method to control concrete shrinkage.

* Corresponding Author Email: j_ahmadi@znu.ac.ir

According to this, in this study the autogenous shrinkage strain of high-strength concrete has been investigated. For this goal, the effects of water-binder ratio, cement and silica fume content and fine to coarse aggregate, on the autogenous shrinkage were discussed.

2. Materials and mixes specification

The cement used for preparation of the specimens was ordinary portland cement type 1 and the maximum size of the aggregate was 19 mm. A naphthalene formaldehyde super-plasticizer was used to maintain the suitable workability of the mixtures. The mix proportions of the concretes are given in table 1.

The total mixing time was approximately 4 min for all mixes. Concrete specimens (80x80mm in cross section and 280 mm length) were cast with various concrete mixes for measurement of concrete shrinkage. The specimens were covered with wet burlap to prevent water loss during the first 24 h after casting. After the molds were removed, the specimens immediately covered with polymer curing material to prevent water loss during the test.

Table 1. the mix proportions

mix	W/C	C	S	G	SF(%)	SP(%)	slump
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.

3. Results and discussion

3.1. Compressive strength

For concrete specimens, the 7 and 28 days compressive strength is shown in table 2. It can be seen that the compressive strength in the specimen with 10% silica fume was higher than the specimen with 0 and 20%.

The mix with sand to gravel ratio of 2 to 3, have lower resistance than the 1 to 1 and 3 to 2 ratios. However the concrete compressive strength of mix design number 4, that has lowest w/c ratio (w/c = 0.3), was higher than the other. From this, it can be concluded that w/c ratio have major effect on the compressive strength of concrete specimens.

3.2. Autogenous shrinkage

The results of the autogenous shrinkage strains of various concrete mixes are illustrated in figures 1 to 4.

Table 2. Compressive strength of concrete specimens (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

The shrinkage strains with different levels of w/c ratio are shown in figure1. According to the test results it is concluded that the autogenous shrinkage strain of mixes increases (32to100%) with decreases of the w/b ratio. The water existence in concrete is required to continue the hydration of cement. This fact was shown clearly in the figure 1.

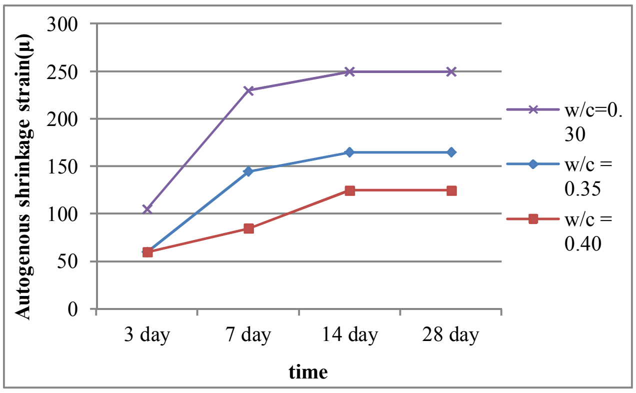

Fig 1 . Variation of autogenous shrinkage strain of H.S.C with W/C ratio

The cement content effects on the autogenous shrinkage is shown figure 2. This figure indicated that high-strength concrete containing higher cement content shows higher autogenous shrinkage strain because of the higher value of hydrated cement paste. Since the shrinkage strains occurs in the paste, then in the concrete with higher value of cement past, greater amounts of shrinkage occurs.

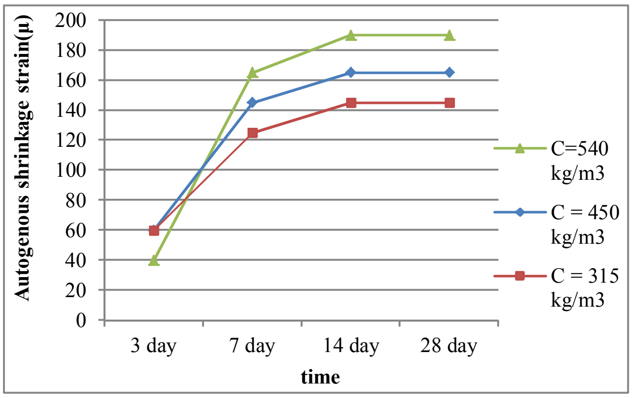

Fig 2 . Variation of Autogenous shrinkage strain of H.S.C with cement content

Figure 3 shows that the additions of 10-20 % of silica fume to the mix increase the autogenous shrinkage strains of concrete specimens. This is because of higher value of specific surface area.

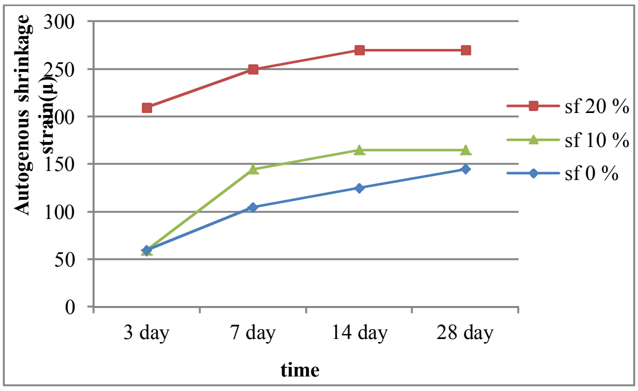

Fig 3 . Variation of autogenous shrinkage strain of H.S.C with SF ratio

The effects of fine to coarse aggregate ratio on the autogenous shrinkage are shown in figure 4. The autogenous shrinkage strain increases slightly with increasing the fine to coarse aggregate ratio.

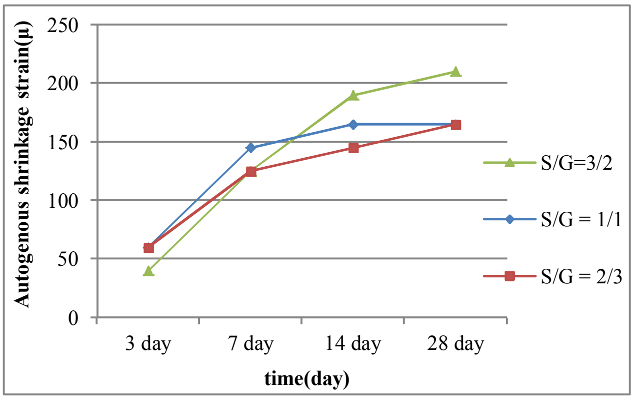

Fig 4 . Variation of autogenous shrinkage strain of H.S.C with S/G ratio

3.3. Autogenous shrinkage prediction models

Four autogenous shrinkage prediction models are investigated in this section. The discussion is concentrated on evaluating the accuracy of these models. This has accomplished by comparing the theoretical results that obtained by these models and experimental data. These models are the CEB FIP MC 90 Model, the JSCE 2002 Model, the Euro Code 2001, and Mazloom Model [6].
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.
This model can be applied for concretes with average 28-day compressive strength ranging from 20 to 90 MPa.
The JSCE 2002 model is recommended by the Japan Concrete Institute. The autogenous shrinkage strains are expressed as functions of time. 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.

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.
The Mazloom model is developed by Mazloom et al. in 2004. In this model, the following factors are considered for prediction of autogenous shrinkage strain: concrete age and silica fume content.
The results for autogenous shrinkage strain are presented in the following figures. The shrinkage strain values were calculated by the four models. Those values were compared against the experimental data obtained for mix 1 to 4 in figures 5 -8.

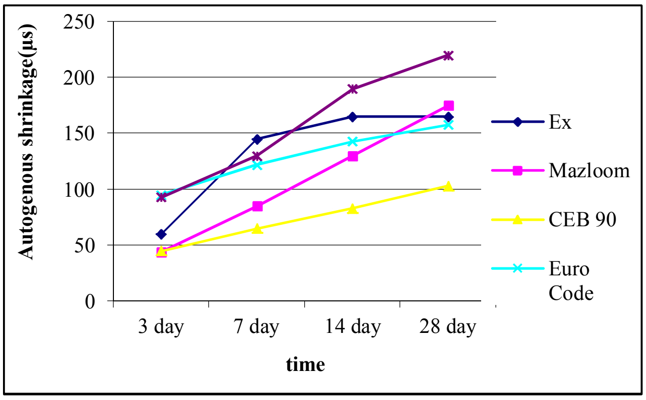

Fig 5. The calculated and obtained value of autogenous shrinkage (mix design 1)

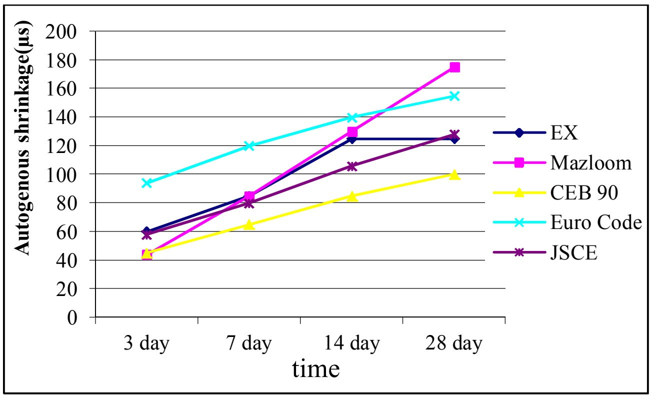

Fig 6. The calculated and obtained value of autogenous shrinkage (mix design 2)

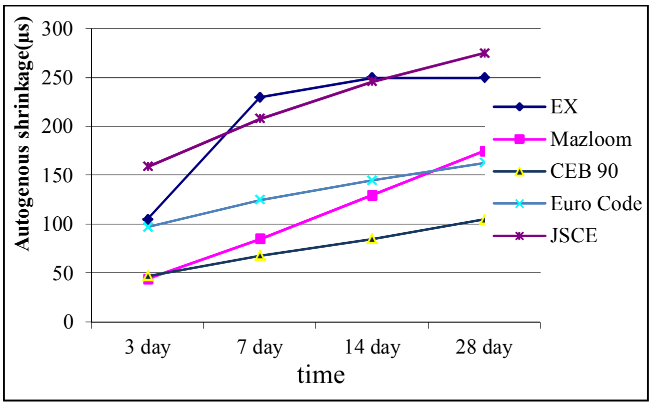

Fig 7. The calculated and obtained value of autogenous shrinkage (mix design 3)

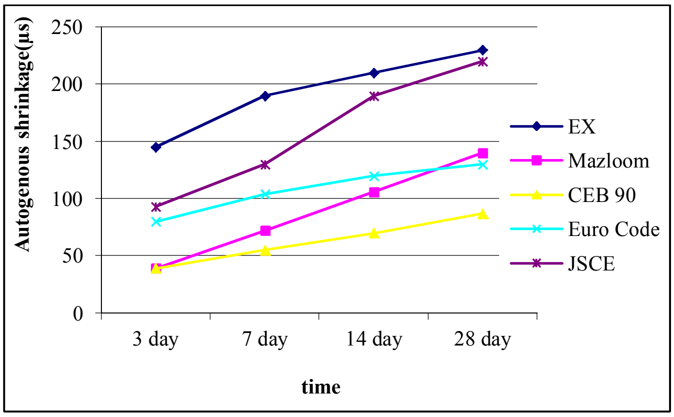

Fig 8. The calculated and obtained value of autogenous shrinkage (mix design 4)

According to these figures and in among the four prediction models, the JSCE 2002 model is more accurate than the others.

4. Conclusions

Based on the results obtained in this investigation the following can be concluded.

The autogenous shrinkage strain of H.P.C increases when the W/C ratio was decreased. Also, The autogenous shrinkage strains of H.P.C with replacement of 10-20 % cement by silica fume at different ages are more than the shrinkage strain of H.P.C without any silica fume.

The autogenous shrinkage strain of H.P.C increases slightly with increasing the cement content and the fine to coarse aggregate ratio. In among the four prediction models, the JSCE 2002 model is more accurate than the others.

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