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Effect of Fly Ash Replacement Content on the Autogenous Shrinkage of Self-Compacting Concrete

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Abstract

Based on an experimental program, autogenous shrinkage of self-compacting concrete (SCC) has been investigated by varied factors such as partial replacement by fly ash content, the unit quantity of binder, and water-binder ratio of mixture design, The results indicate that the autogenous shrinkage of self-compacting concrete decreases with increasing fly ash content and water-binder ratio and that when the unit quantity of binder is 550 kg/m3, the autogenous shrinkage of self-compacting concrete is smaller than that with unit binder quantity of 500 kg/m3 or 600 kg/m3. These observations suggest that a good correlation exists between the autogenous shrinkage and the mineral mixture design.

Keywords: self-compacting concrete; autogenous shrinkage; mixture design; fly- ash; binder; water-binder ratio, industrial wastes

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1. Introduction

Self-compacting concrete (SCC) is a novel type of concrete innovated in Japan. It does not demand manual compaction and has adequate mobility without aggregate segregation if placed from certain height. SCC has the filling potential and the necessary fluidity needed to flow through packed reinforcement detailing without precipitation [1]. Due to the fact that it does not necessitate vibration to compact, resulting in reducing the concrete casting costs, improvement of working conditions and barring of health hazards generated from vibrations [2]. Conventionally, to obtain excellent rheological properties, high proportions of mineral admixtures are used in SCC as part of binder material like fly ash [3-6]. SCC has a low water/binder ratio or a large portion of binder, which is expected to increase its autogenous shrinkage [7]. Researchers has been found that autogenous shrinkage increases with increasing quantity of binder and decreasing water-binder ratio on cement paste [8, 9] However, it is possible that the autogenous shrinkage of SCC is greatly influenced by the fly ash content in the mixture design since the cement used in SCC is less than that of normal concrete. Hence, it is substantial to understand the relationship between the fly ash content and autogenous shrinkage of SCC.

High-performance cementitious materials can be susceptible to early age cracking resulting from high autogenous shrinkage values. Autogenous shrinkage is interpreted as the external-macroscopically (bulk) dimensional shortening (volume or linear) of the cementitious material system, which arises under sealed isothermal unrestrained conditions [1]. The development autogenous shrinkage is fundamentally regard to the low water/binder ratio. However, the incorporation of fine powders like silica fume and fly ash can have a pivotal role [2, 10]. Autogenous shrinkage is the consequence of the chemical shrinkage proceeding during the cement hydration process. In fluid approach of the cementitious material, the chemical shrinkage is entirely transformed into autogenous shrinkage. As soon as the cementitious material exhibits a filtering cluster of hydration products, the free chemical shrinkage is hampered and the autogenous shrinkage diverges from the chemical shrinkage [11, 12]. At this level, the autogenous shrinkage is affected by various mechanisms: disjoining pressure, changes in the surface tension of the solid gel particles, and capillary tension.[13]

The commencement of cluster evolution of the hydration products signs the start of internal stress generation due to the autogenous shrinkage. The establishment of this specific percolation threshold is not straightforward, and several approaches have been pursued: according to the strength development, Vicat needle test, development of heat of hydration, ultrasonic testing of the fresh concrete. [14-16]

Aside from the effect of increased paste volume, the autogenous shrinkage is also governed by changes in the capillary network owing to the presence of mineral additions like fly ash. The modification in pore structure of capillaries prompts a change in amount of self-desiccation shrinkage [16-19]. Few research has been utilized and reviewed the influence of industrial by-products materials as sustainable replacements such as flyash, coal bottom, copper slag...etc. on the plastic deformations of SCC with ternary blend formulations and thus on overall satisfactory development of concrete [20-23]. A comprehensive conception of the effect of the mix design with partial replacement of mineral content like fly ash on autogenous shrinkage is still insufficient. Hence, this work is aimed to investigate this effect, which will be beneficial to tailor SCC with volume stability. In this paper, the effect of partial replacement by fly ash content, the unit quantity of binder, and water-binder ratio of mixture design autogenous shrinkage is experimentally conducted.

2. Experimental program

2.1. Materials

Grade 42.5R (Chinese cement grading system) Portland cement, manufactured in Fujian Province, China was used for making concrete. Its physical properties and chemical composition are given in Table 1, and the information was provided by the supplier. The fly ash used was dry, uncompacted powder produced by Xiamen Power Plant with apparent density of 2200kg/m3. Detailed physical properties and chemical composition are also given in Table 1. The coarse aggregate used in SCC was crushed granite with a maximum size of 20mm. Natural River sand with a fineness modulus of 2.70 and an apparent density of 2650kg/m3 was adopted as the fine aggregate. A superplasticizer (SP) TW-4 (Sulfonated naphthalene formaldehyde type) with a water-reducing ratio of 25% was used in this study

Physical properties	Cement	Fly ash
Specific surface (cm^2/g)	3011	2600
Apparent density (kg/m^3)	3100.00	2200
Degree of fineness (%)	0.60	-
Chemical composition (%)		
CaO	64.09	6.28
SiO_2	20.43	48.33
Al_2O_3	5.34	34.79
Fe_2O_3	3.96	5.96
SO_3	3.55	0.83
MgO	1.09	1.08
K_2O	1.00	0.89
TiO_2	0.29	1.68
MnO	0.10	-
P_2O_3	0.01	0.10
LOSS	1.38	1.38

Table 1 Physical properties and chemical composition of cement and fly ash

2.2. Mixture proportions

Mixture proportions of the self-compacting concrete studied are given in Table 2. The water-binder (w/b) ratio of the self-compacting concrete ranged from 0.28 to 0.42, and the fly ash content ranged from 0% to 54% by mass of the total cementitious materials

2.3. Slump and Compressive Strength

The self-compacting concrete was mixed in a laboratory drum mixer. The coarse and fine aggregates were mixed first, followed by the addition of fly ash and cement. After the materials were dispersed uniformly, the superplasticizer and water were added and mixed together until a consistent mixture was obtained. According to Chinese Code GB/T 50080-2002 [24], the slump of the fresh self-compacting concrete was determined immediately after the mixing, and was controlled within the range of 250-270 mm as presented in Table 3. For each self-compacting concrete mixture, six 150×150×150-mm cubes were cast for the cubic compressive strength of 7d and 28d and were measured per Chinese Code GB/T 50081-2002[25] three prisms of 100×100×515 mm was cast for determining the autogenous shrinkage. After casting, all the cubes and prisms for the cubes and prisms for the autogenous shrinkage measurement were left in the casting room (~25°C), covered with plastic sheet for approximately 24h, then demolded and cured in a moist-curing room at 20±3°C and 60±5% relative humidity until it is time for testing. The compressive strength of the self-compacting concrete was determined after 7 days and 28 days of moist curing and tabulated in Table 3.

Mix no.	Cement	Fly ash	Water	Sand	Stone	Superplasticizer	Binder	w/b	s/a
SCC-1	550	0	178	780	850	6.0	550	0.32	0.48
SCC-2	450	100	178	780	850	5.4	550	0.32	0.48
SCC-3	350	200	178	780	850	5.8	550	0.32	0.48
SCC-4	250	300	178	780	850	5.7	550	0.32	0.48
SCC-5	318	182	162	812	884	4.2	500	0.32	0.48
SCC-6	382	218	194	748	816	4.8	600	0.32	0.48
SCC-7	350	200	154	780	850	5.8	550	0.28	0.48
SCC-8	350	200	198	780	850	4.5	550	0.36	0.48
SCC-9	350	200	231	780	850	4.0	550	0.42	0.48

Table 2. Actual concrete mixture proportions for 1 m3 concrete (in kg/m3)

Mix no.	Compressive strength (MPa)		Slump (mm)
	7d	28d	
SCC-1	55.9	67.0	258
SCC-2	47.5	64.3	262
SCC-3	38.4	57.3	264
SCC-4	30.3	49.0	269
SCC-5	44.5	66.2	260
SCC-6	42.6	59.9	267
SCC-7	45.9	65.8	261
SCC-8	32.2	49.7	265
SCC-9	23.3	42.1	269

Table 3 Slump and compressive strength of the self-compacting concrete

For each autogenous shrinkage measurement, a thermocouple and a strain transducer were pre-embedded in the center of the prism horizontally (Figure1). And two eddy current probes were tied onto the magnetic bases. The interior surfaces of the steel molds were lined with a layer of smooth polymer material to reduce the friction between the prisms and the molds. Immediately after the self-compacting concrete casting, each prism with the steel mold was sealed individually in a plastic sheet and kept at ~20℃ for the entire period of experiment except for the first 24 hours.

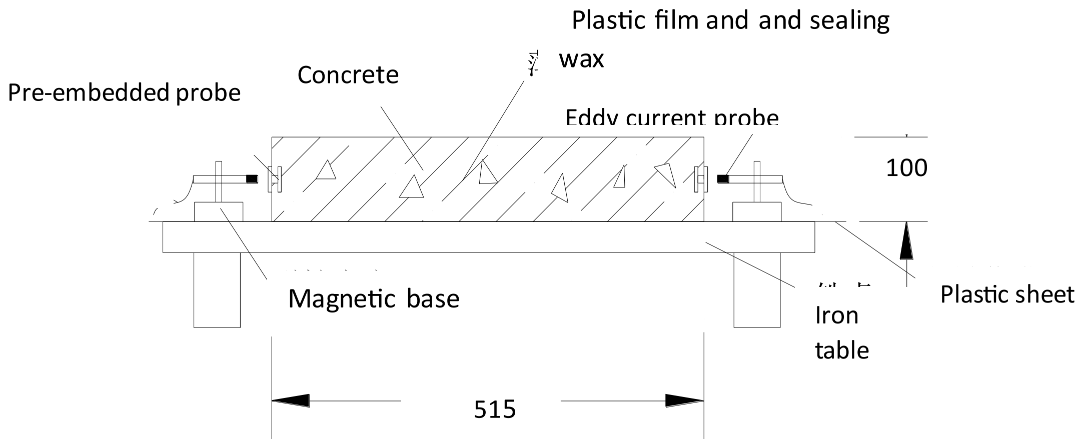

Figure1. Schematic view of autogenous shrinkage test setup (unit: mm)

2.4. Measurement of autogenous shrinkage

The strain transducer and thermocouple embedded in each self-compacting concrete prism were connected to a data logger controlled by computer (Figure 2) about 24 hours after the casting of the self-compacting concrete specimen, and the shrinkage strain and temperature variation of the concrete specimen with time were recorded.

The embedded strain transducers used in the experiment (Shanghai Fushang Electronic Co., FS8000 series) can measure the strain of self-compacting concrete that undergoes a transition from compliant to hardened state

The measured data or values obtained from the computer directly included the shrinkage values before calibration and the temperature variation with time. The beginning of the shrinkage observed was used as a reference value. Subsequent values obtained were subtracted from the reference values and multiplied by the calibration coefficient of the transducer to obtain the autogenous shrinkage.

The calibration coefficient for each strain transducer was obtained from the manufacturer's test data table. The strain transducer is calibrated by connecting the input/output cable to the strain meter having the constant voltage bridge excitation. Calibration coefficient and zero balance are obtained by setting the gauge factor of strain meter to 2, rate output. Each strain transducer has a different calibration coefficient. And it will be multiplied by the difference between the measured value and the reference value to obtain the autogenous shrinkage.

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(a) Stereogram of the test setup (b) Data acquisition system

Figure2. Test setup of autogenous shrinkage of self-compacting concrete

3. Results and discussion

3.1. Effect of fly ash content on autogenous shrinka

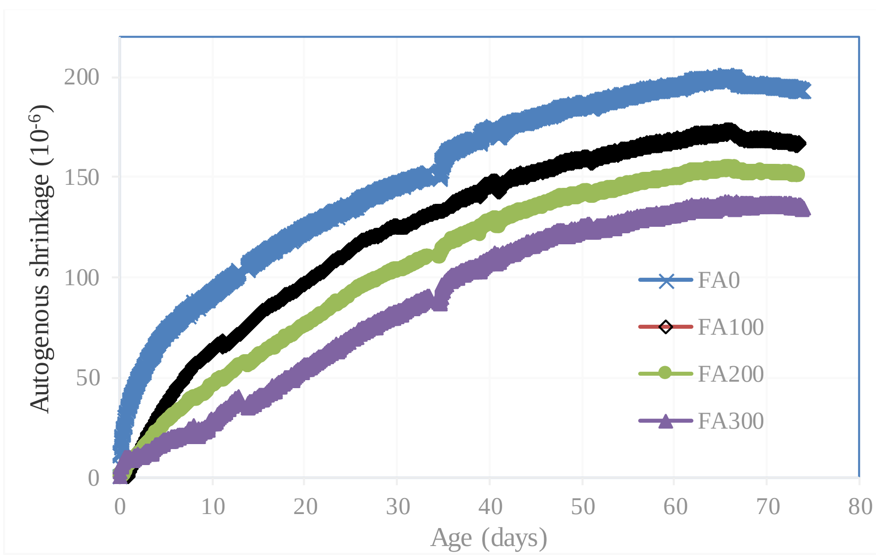

Figure 3. Effect of fly ash content on autogenous shrinkage

The autogenous shrinkage of specimens containing varying fly ash contents is shown in Figure3. Three specimens with varying fly ash showed similar volume changes. 35% of the autogenous shrinkage strain up to 60 days occurred in the first 2 weeks after concrete casting. And about 50% or more of the autogenous shrinkage strain up to 60 days occurred in the first month. Autogenous shrinkage decreases with increasing fly ash content. A growth of fly ash content from 0 kg/m3 (0% cement replaced) to 100 kg/m3 (18% cement replaced) resulted in a decrease in the autogenous shrinkage from 195 to 168 micro strains at 60 days, while a further growth of fly ash content to 200 kg/m3 (36% cement replaced) and 300 kg/m3 (54% cement replaced) decreased the autogenous shrinkage to 151 and 133 micro strains.

3.2. Effect of unit quantity of binder on autogenous shrinkage

Figure 4 shows the relationship between the unit quantity of binder and autogenous shrinkage. For all the three specimens with unit contents of 500, 550 and 600 kg/m3, swelled slightly during the early stages. Autogenous shrinkage was the smallest for the specimen containing 550 kg/m3; smaller than that for the specimen containing 500 kg/m3 or 600 kg/m3. The autogenous shrinkage reached about 151 micro strains at 60 days. While the autogenous shrinkage for the specimens with unit contents of 500 and 600 kg/m3, reached about 181 and 217 micro strains at 60 days respectively.

From Figure 4, it can be noted that autogenous shrinkage of self-compacting concrete decreases with increasing unit quantity of binder of self-compacting concrete. This is related directly to that when the amount of binder increases, the ability of enveloping aggregates is enhanced, the contact interface become dense, the density of concrete be improved, and the autogenous shrinkage of concrete will be reduced. While when unit quantity of binder reaches 600 kg/m3, autogenous shrinkage of self-compacting concrete increases. Due to the reduction of the aggregate content, the binding force of aggregate to the self-compact concrete decreases, which leads to the increase of autogenous shrinkage.

Figure5. depicts the relationship between the water-binder (w/b) ratio of self-compacting concrete and autogenous shrinkage. It appears that the w/b ratio had significant effect on the autogenous shrinkage strain of the self-compacting concrete. The autogenous shrinkage decreased with increasing w/b ratio. For the control water/binder ratio, a growth of w/b ratio from 0.28 to 0.32 resulted in a decrease in the autogenous shrinkage from 165 to 151 micro strains at 60 days, while a further growth of w/b ratio to 0.36 and 0.42 decreased the autogenous shrinkage to 126 and 101micro strains respectively. From Figure 4, it could be found that autogenous shrinkage of self-compacting concrete decreases with increasing w/b ratio.

4. Conclusions

The beneficial use of industrial by-products ashes as partial substitution in concrete mix design to eliminate the effect of autogenous shrinkage and maintain on the same time on other desired properties for development of concrete; workability, strength,etc was carried out in this study. The findings were summarized as below:

1. Autogenous shrinkage of self-compacting concrete decreases with increasing fly ash content and water-binder ratio of self-compacting concrete.
2. Autogenous shrinkage of self-compacting concrete decreases with increasing unit quantity of binder of self-compacting concrete when the unit quantity of binder is below 550kg/m3. However, when the unit quantity of binder is above 550kg/m3, the autogenous shrinkage of self-compacting concrete increases with increasing unit quantity of binder of self-compacting concrete.

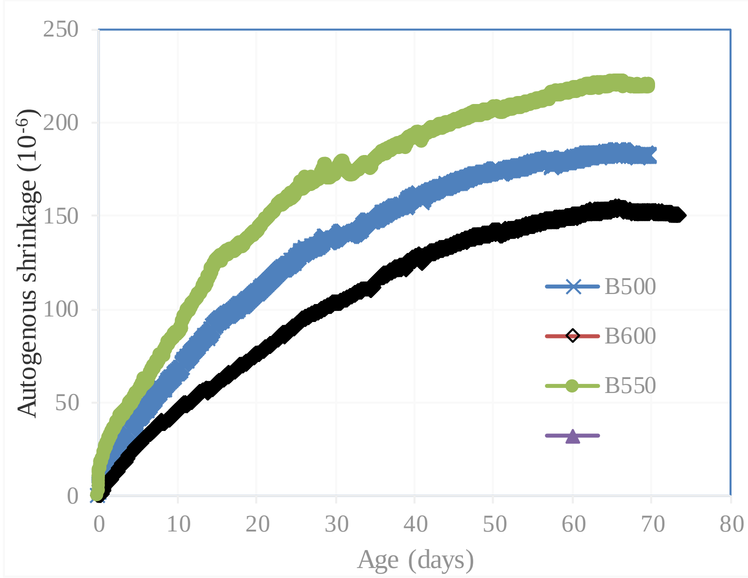

Figure 4. Effect of unit quantity of binder on autogenous shrinkage

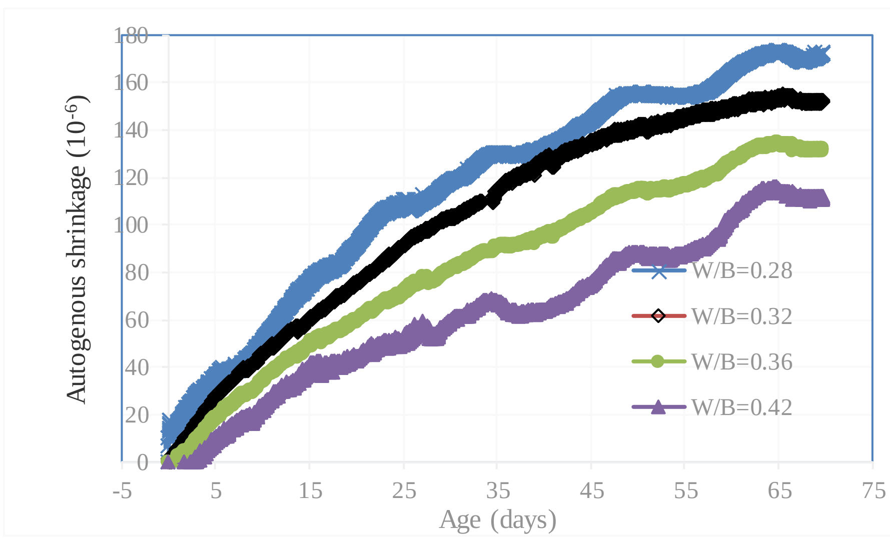

Figure 5. Effect of water-binder ratio on autogenous shrinkage

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