2015

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ABSTRACT

The shotcrete used in a landscape infrastructures would have a big surface exposed to air and this would increase the possibility of cracking. Furthermore, the prohibition of curing agent spray to the exposed surface of a landscape infrastructure after shooting, because of staining, would aggravate cracking. Therefore, the feasibility of cracking is more likely to increase. The shrinkages from plastic, autogenous and dry could cause a contraction cracking of the high-performance shotcrete.

In this study, expansion admixture was used to suppress the cracking of high performance shotcrete. The effect of expansion admixture on the high-performance shotcrete was investigated. The fly ash was incorporated as a rates of 0%, 10%, 20%, 30% and 40% and the expansive admixture was incorporated as 11%. The results are as follows:

It could be deduced that when Portland cement, fly ash and expansive agents are mixed altogether as in the percentage presented in this research, the shotcrete mass expands in very early hours. In the case of restrained shotcrete mass, this expansion would lead for stress development since free expansion is not possible in restrained situations. This expansion behavior is believed to be due to the expansive behavior of expansive agent and a high hydration heat reaction taking place in the mass which in turn led for an increase in temperature in the shotcrete mass.

The shotcrete mass thermally expands as the temperature increases. The temperature due to hydration reaction rapidly increases in the first 12 hours. And then gradually shrinks. This is due to the cooling of hydration reaction in the mass, and due to capillary pressure.

It can be seen that the shotcrete mass with expansive agent has a higher magnitude and rate of expansion. Furthermore, it could be noticed that, as the percentage of fly ash increases, the early age expansion decreases significantly. This leads to the conclusion that increasing the percentage of fly ash significantly decreases the early age volume change.

Key Words: early-age behavior, shrinkage, shotcrete, expansive admixture

1. INTRODUCTION

Shrinkage, from age-stage points of view could be classified in to two principal stages; early age shrinkage and long term shrinkage (or drying shrinkage). The earlier is the change in volume of shotcrete due to some chemical, structural and hydration heat reactions and occurs at the early age while the later means the change in volume of shotcrete in the long term mainly due to loss of water to the environment and is eternal process.

Early age shrinkage also known as autogenous shrinkage has only recently been documented and accurately measured. It was first described in the 1930's (Lyman 1934) as a factor contributing to the total shrinkage, which was difficult to assess. The volume of concrete begins to change shortly after it is cast and any volume changes at early age i.e., within 24-72 hours, can induce tensile stress and crack formation in hardened concrete [Erika E. Holt, 2001].

Early age shrinkage has some three phases and these are; liquid phase, skeleton formation phase and hardening phases (Erika E. Holt 2001). A brief introduction on these phases is presented below.

(1) Liquid phase (Plastic): After shotcrete is mixed, pumped and shoot onto the substrate surface, it still remains in liquid (plastic) state for very short period of time depending on the mix composition and ambient conditions. It is believed that no harmful shrinkage happens at this stage because the material is still fluid/ plastic. In this early phase while the concrete is still liquid the autogenous shrinkage is equivalent to chemical shrinkage (Erica. E. Holt, 2001). This early age shrinkage is sometimes referred as plastic shrinkage. Plastic shrinkage, as the name implies, occurs in the plastic state of concrete soon after the concrete is placed but until concrete sets. It is argued that plastic shrinkage occurs due to Loss of water by evaporation from the surface of concrete or absorption by aggregate. This loss of water results the reduction of volume, which in turn may create at the surface or internally around the aggregate or reinforcement. Setting terminates plastic shrinkage.

(2) Skeleton formation stage: In this stage/phase the shotcrete gradually starts developing early stiffening and strength due the chemical reaction between cement, water, aggregates and other added minerals such as fly ash, silica fume and etc. It is in this stage where the initial setting and early age shrinkage believed to emerge.

(3) Hardening stage: At this stage, the concrete stiffens and can resist most shrinkage stresses and standard long term shrinkage is believed to start at this stage. Kronlöf and others (1995) and Holt (2001) noted that approximately 2 hours after the initial setting time, the concrete can usually withstand the drying shrinkage forces. Cracking may occur at this stage if the concrete doesn't develop enough strength to withstand the stress.

In this study, early age shrinkage of shotcrete is defined as the volume changes occurring in the first 62 hours (approximately) immediately after initial setting of shotcrete. That means, this research does not consider the shrinkage (plastic shrinkage) before initial setting. Initial setting time, which is the time elapsed till the shotcrete initially sets, is obviously different for each different mix. In this research the initial setting time of all the mixes ranges approximately from four to six hours. The initial setting time for each mix was performed by VCAT needle test in accordance with the American Society of Testing Materials (ASTM).

2. EXPERIMENTAL PROGRAM

2-1 Materials

(1) Cement

The type of cement used in this research was Ordinary Portland Cement (OPC). The physic-chemical property of the OPC is as follows: The fineness is 3,449 cm^2/g; the specific gravity is 3.15; the initial and final setting tome is 245 minutes and 5hours 40 minutes, respectively.

(2) Aggregates

The coarse aggregate (crushed stone) used in the research has a maximum size of 10mm and the fine aggregate which is locally available river sand with a size of 5mm was used. The specific gravities of coarse aggregate and fine aggregates were 2.60 and 2.64, respectively. The absorption of coarse aggregate and fine aggregates were 1.14% and 1.27%, respectively.

(3) Expansive Admixture

The expansive agent used was manufactured by S company and it is CSA expansive admixture type. The chemical properties is shown in Table 2.1.

Table 2.1 Chemical property of expansive agent

Constituent	SiO_2	Al_2O_3	CaO	MgO	R_2O	SO_3	F-CaO	LOI
Proportion (%)	≥5.0	10-15	48-53	≥1.5	≥1.0	27-32	18-23	≥3.0

(4) Fly Ash

The fly ash, as per KS L 5405 ordinary fly ash was used and the chemical composition is as follows: C is 16.8%; Al_2O_3 is 22.9%, CaO is 4.95%; Fe_2O_3 is 1.84%; SiO_2 is 41.5%.

2-2 Equipment

(1) Shotcrete Mixer and Pump

The equipment used for mixing and pumping was the Allentown combination mixer-Pump type manufactured by Allentown shotcrete Technology. It consists of a mixer mounted at behind for blending cementitious material, aggregate and water, and a two piston pump mounted at the front to provide smooth flow of shotcrete into the pipe line. The pump is driven by 2 pistons, having a maximum material pressure of 122bar and mixer capacity of 280L.

(2) Air Compressor

The machine, model PDS 390S, made by Hokuetsu Industries Co.Ltd, which supplies compressed air was used. This machine is situated nearby the shotcrete machine. The hose from the compressed air supplier machine which carries the compressed air was fastened at the nozzle or at the exit of shotcrete so as to shot the shotcrete with a high pressure onto the substrate surface.

2-3 Mixture Design

In this research, the water to binding material ratio (W/B) was set to be 40% while the sand to aggregate ratio (S/a) as 65%. For instance, the control mix (OPC-FA00-EA00) has 180 Kg/m^3 of water, 460 Kg/m^3 of cement, 912.5 Kg/m^3 of sand and 491.4 Kg/m^3 of coarse aggregate. For the rest of mixtures, different dosages of fly ash i.e., 0%, 10%, 20%, 30% and 40% and 11% of expansive agent were used. In addition, 0.03% of Air Entraining Agent (AEA) and 0.3% of Super Plasticizers (SP) were used in all mixtures. The following table summarizes the mix design.

Table 2.3 Mixture design

Mixture	Slump (mm)	AC (%)	W/B (%)	S/a (%)	Unit weight (Kg/m^3)						AEA (Kg/ m^3)	SP Kg/ m^3)
					W	C	S	G	FA	EA		
FA00-EA00	120	7.0	40	65	184	460	912.5	491.4	0.0	0.0	0.138 (0.03%	1.38 (0.3%)
FA00-EA11	80	5.5	40	65	184	409.4	943.4	508.0	0.0	50.6	0.138	1.38
FA10-EA11	115	2.5	40	65	184	363.4	897.7	483.4	46	50.6	0.138	1.38
FA20-EA11	100	2.0	40	65	184	317.4	886.2	477.2	92	50.6	0.138	1.38
FA30-EA11	90	1.0	40	65	184	271.4	925.4	498.3	138	50.6	0.138	1.38
FA40-EA11	80	2.0	40	65	184	225.4	913.9	492.1	184	50.6	0.138	1.38
FA10-EA00	110	2.5	40	65	184	414	901.9	485.6	46	0.0	0.138	1.38
FA20-EA00	100	2.0	40	65	184	368	889.6	479.0	92	0.0	0.138	1.38
FA30-EA00	130	2.0	40	65	184	322	880.6	474.2	138	0.0	0.138	1.38
FA40-EA00	130	2.5	40	65	184	276	869.9	468.4	184	0.0	0.138	1.38

AC= Air Content, W= Water, C=Cement, S =Sand, G= Coarse aggregate, FA= Fly ash, EA= Expansive agent, AEA= Air Entraining Agent, SP= Super Plasticizer

2-4 Early-age Shrinkage Test

Early age shrinkage is measured as length change and this change in length can be measured by a Linear Variable Differential Transformer (LVDT) inserted at each end of the specimen. However, in order to get accurate results the end inserts where the LVDT is connected have to be free to move without any resistance from the sides of the mold. And secondly; the shotcrete has to be free to move without resistance from the sides of the mold.

Mixture samples were placed in the early age shrinkage mold right after shotcrete shooting (three replicates for each mix). These specimens were sealed well by plastic sheets and Plexiglas so that there would not be any moisture transfer. When initial setting was ready, the early age shrinkage apparatus was turned on and started registering data for approximately 62 hours since initial setting. The test room temperature and relative humidity was 20 ± 2^{o}C and 60 ± 5% respectively.

In this research, the change in length in the shotcrete was performed using 10mm LVDT machine, which can measure any change in length with a precision of 0.001mm and store any change in length in the data logger machine. Fig 2.1 shows the schematic setup.

Three square prism specimens (for each mixture) with dimensions of 64W X 70H X 314L (Figure 2.2) were used to determine shotcrete's shrinkage at early age.

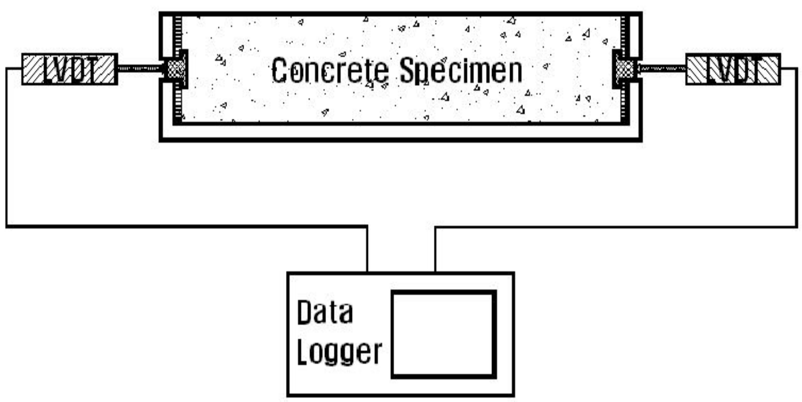

Figure 2.1 Schematics of test setup for measuring early age shrinkage

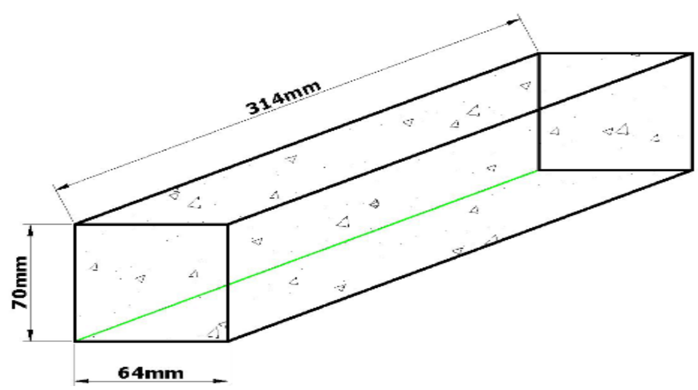

Figure 2.2. Mold for early age shrinkage test

3. EXPERIMENTAL RESULTS AND DISCUSSION

3-1 Fly ash and Expansive agent mixtures

These types of mixtures were composed of expansive agent at constant dosage (11%) and different dosages of fly ash (10, 20, 30 and 40%). Test results are shown in the Figure 3.1. As it can be seen in the figure, in all the mixes, the shotcrete mass expands in early hours. After approximately 40 hours since initial setting, the mixes tend to maintain its expanded volume and carry on. This expansion has maximum value at mixture designation FA20-EA11. Moreover, it could be seen that the magnitude and rate of expansion decreased as the percentage of fly ash increased, except for the FA10-EA11 mixture which differently has a lower expansion magnitude.

It could be deduced that when Portland cement, fly ash and expansive agents are mixed altogether as in the percentage presented in this research, the shotcrete mass expands in very early hours. In the case of restrained shotcrete mass, this expansion would lead for stress development since free expansion is not possible in restrained situations. This expansion behavior is believed to be due to the expansive behavior of expansive agent and a high hydration heat reaction taking place in the mass which in turn led for an increase in temperature in the shotcrete mass. An increase in temperature in the concrete mass means an increase in volume of shotcrete mass. However, except the 40 percent fly ash mix, other mix's gradual increment of thermal expansion becomes stable with in the first 40 hours since initial setting.

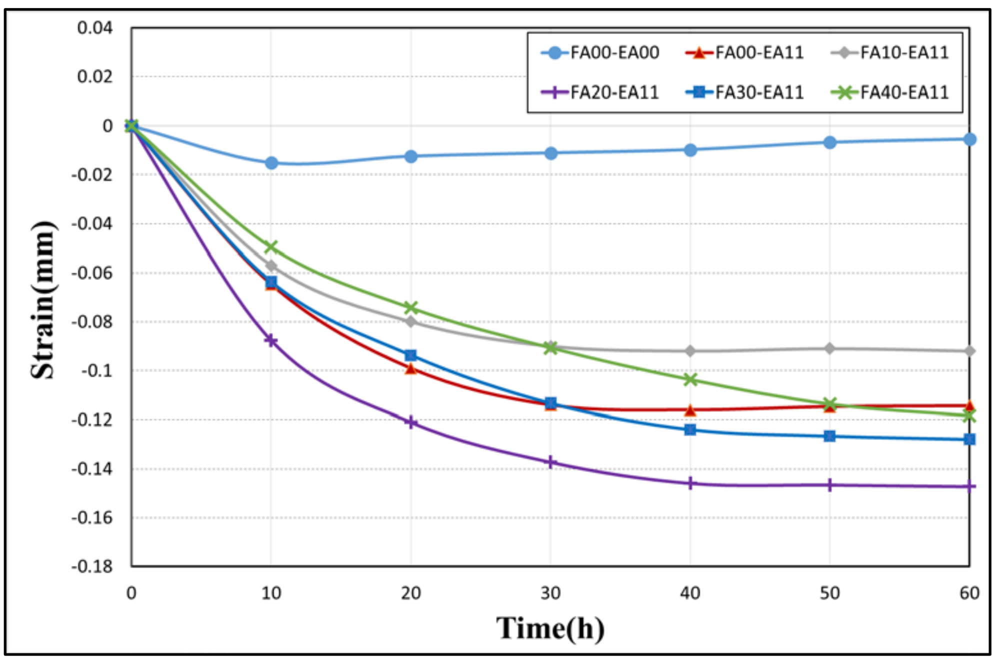

Figure 3.1 Early age shrinkage of Fly ash and Expansive mixtures

3-2 Fly ash mixtures

These mixtures were composed of no expansive admixtures but different dosages of fly ash (10, 20, 30, and 40%). A test result of these mixtures is shown in Figure 3.2. For all mixes, as it can be seen in the fig, the shotcrete mass expands sharply in the first 8-12 hours. This is believed to be due to the hydration reaction between the cementitious materials and water. The shotcrete mass thermally expands as the temperature increases. The temperature due to hydration reaction rapidly increases in the first 12 hours. And then gradually shrinks. This is due to the cooling of hydration reaction in the mass, and due to capillary pressure. Now the mass is cooling since the heat is gradually declining. This thermal contraction leads the shotcrete mass to shrink. This rapid recover in volume leads for shotcrete shrinkage and could possibly create micro cracks.

The test results further show that as the percentage of fly ash increases the expansion gets lower and lower. This is due to the chemical property of fly ash, lower hydration heat reaction. And hence increasing the percentage of fly ash would minimize the magnitude of expansion and shrinkage in such a way that by reducing hydration heat reaction thereby minimizing temperature.

In order to compare and contrast the effect of fly ash on the early age shrinkage of shotcrete, independent early age shrinkage results of different mixes are compared one another. Figure 3.3 compares the results of mixtures. As it can be clearly seen the difference in the magnitude and rate of expansion between the two mixtures becomes higher as time passes. This is clearly due to the property of the expansive agent.

Furthermore, the figs below show comparisons of Fly ash- Expansive agent mixtures and Fly ash mixtures. It can be seen that the shotcrete mass with expansive agent has a higher magnitude and rate of expansion for the same reason mentioned above (due to the expansive nature of expansive agent). Furthermore, it could be noticed that, as the percentage of fly ash increases (but when expansive agent is not used), the early age expansion decreases significantly. This leads to the conclusion that increasing the percentage of fly ash significantly decreases the early age volume change.

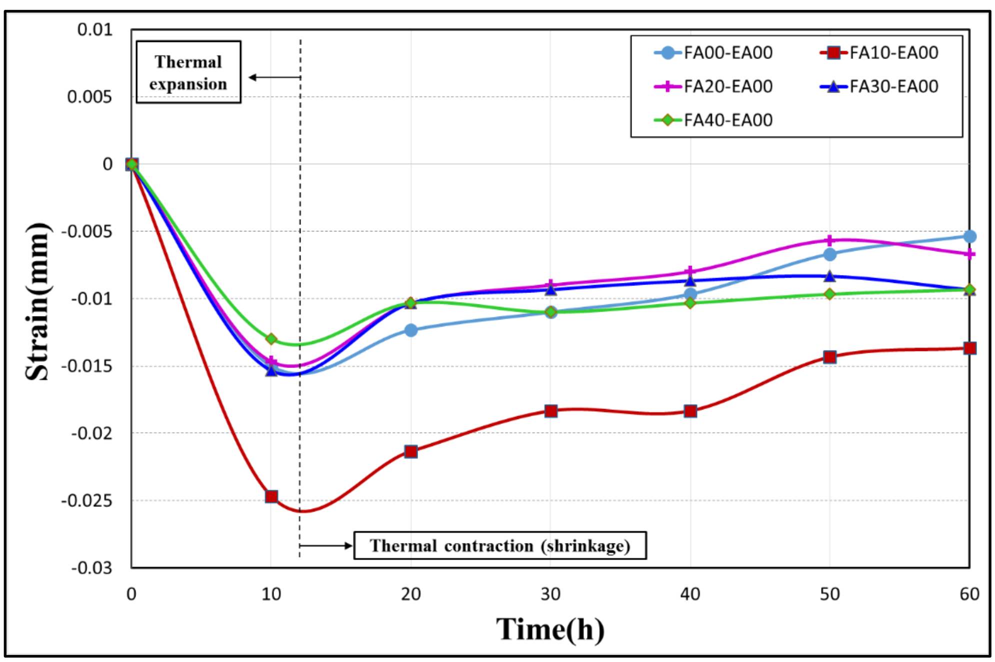

Figure 3.2 Thermal expansion and contraction of fly ash mixed shotcrete mass

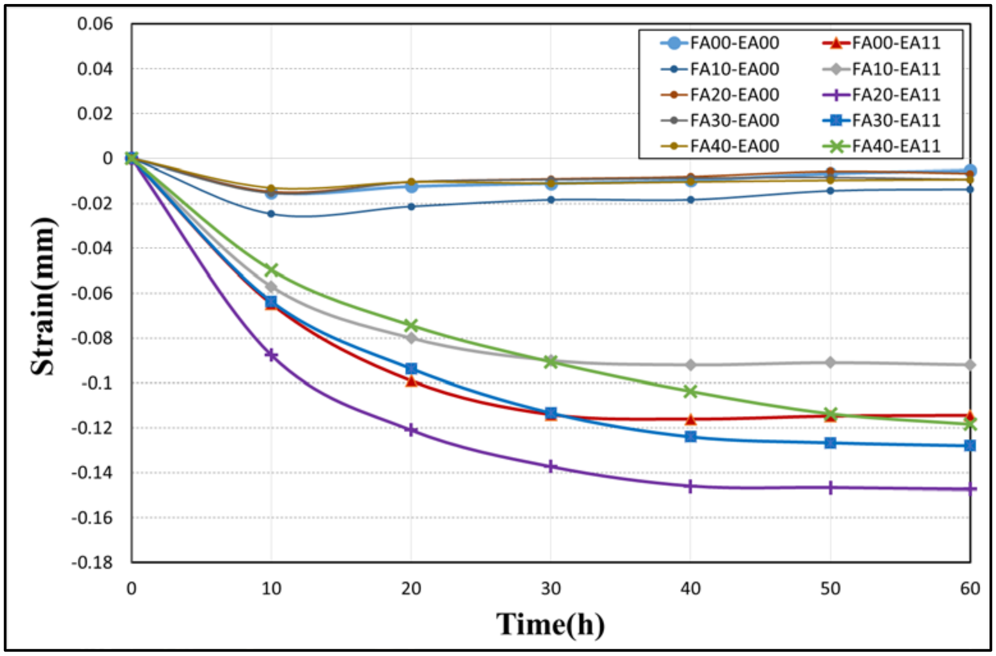

Figure 3.1 Comparison of Shrinkage with and without Expansive admixture

4. CONCLUSION

It could be deduced that when Portland cement, fly ash and expansive agents are mixed altogether as in the percentage presented in this research, the shotcrete mass expands in very early hours. In the case of restrained shotcrete mass, this expansion would lead for stress development since free expansion is not possible in restrained situations. This expansion behavior is believed to be due to the expansive behavior of expansive agent and a high hydration heat reaction taking place in the mass which in turn led for an increase in temperature in the shotcrete mass.

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