- Technical Paper -

STUDY ON REDUCTION OF SHRINKAGE OF HIGH PERFORMANCE CONCRETE

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ABSTRACT

This study investigates the effects of the use of expansive additives and shrinkage reducing agents on the shrinkage properties of high performance concrete. Results revealed that the combined use of expansive additives and shrinkage reducing agents appeared to produce enhanced shrinkage reducing effect than the use of each admixture individually. And, the combination of 5% expansive additive and 1% shrinkage reducing agent is seen to have no bad influence on the workability and strength and, to reduce shrinkage by about 50%.

Keywords: high performance concrete, autogenous shrinkage, drying shrinkage, expansive additives, shrinkage reducing agents

1. INTRODUCTION

Recently, active researches are conducted on high performance concrete(HPC) exhibiting high strength and high fluidity. These researches are resulting in increased applications on real structures. In order to satisfy the required performances, HPC makes use of large quantities of binder and presents low water-cementitious material ratio(W/B). Such mixing is increasing significantly the autogenous shrinkage, which subsequently is likely to favor the potential development of cracks[1]. Besides, even if large quantities of expansive additives and shrinkage reducing agents are introduced to reduce shrinkage, systematic studies investigating the effects of such materials on HPC are still insufficient.

Accordingly, this study, as part of a research aiming the development of shrinkage reducing technologies of HPC, investigates the effects of the use of expansive additives and shrinkage reducing agents on the drying and autogenous shrinkages of HPC presenting W/B of 30%.

2. TEST PROGRAMS

2.1 Test Variables

The tests examined at first the effects of expansive additives and shrinkage reducing agents on 100×100×400mm specimens, and evaluated then the shrinkage properties of 800×800×800mm mock-up specimens for several mix proportions.

2.2 Materials

The cement adopted in the tests is an ordinary Portland cement (OPC) and, fly ash (FA) and silica fume (SF) are used as mineral admixture. Their physical and chemical properties are listed in Table 1. The expansive additives (EA) is of CSA (calcium sulfate aluminate) type with properties summarized in Table 2, and the shrinkage reducing agents (SR) is a powdered glycol-type agents (density 3.18g/cm^3). The coarse aggregates are crushed stones with maximum size of 20mm (density 2.67g/cm^3), and the fine aggregates are river sand (density 2.63g/cm^3). In order to secure the required fluidity, naphthalene-type superplasticizer is adopted. Air entraining admixture is also admixed to achieve the required air content.

2.3 Mix Proportions

Table 3 lists the reference mix proportions of the HPC adopted in this study. For a concrete with W/B of 30% substituting simultaneously 20% fly ash and 10% silica fume, a total of 25 blending cases were examined combining 5 cases of expansive additives (0, 2.5, 5.0, 7.5, 10.0%) and 5 cases of shrinkage reducing agent (0, 0.5, 1.0, 1.5, 2.0%).

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Table 1 Properties of cement and mineral admixtures

Items / Types	Fineness (cm^2/g)	Density (g/cm^3)	Chemical composition (%)					
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
Cement	3,413	3.15	21.01	6.40	3.12	61.33	3.02	2.14
Silica fume	240,000	2.10	96.00	0.25	0.12	0.38	0.1	-
Fly ash	3,850	2.13	59.32	18.6	5.58	4.43	0.82	0.51

Table 2 Properties of expansive additives

Items / Types	Fineness (cm^2/g)	Density (g/cm^3)	Chemical composition (%)					
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
Expansive additive	3,117	2.98	3.80	28.66	13.55	51.35	0.56	16.02

Table 3 Mix proportions of concrete

W/B (%)	s/a (%)	Target slump flow (mm)	Target air content (%)	Unit content (kg/m^3)						SP (B×wt.%)	AE (B×wt.%)
				W	B			S	G		
					C	FA	SF				
30	45	60±100	4.5±1.5	175	408	117	58	686	814	0.9	0.04

In order to obtain the target slump flow of 600±100mm and the target air content of 4.5±1.5%, the quantities of superplasticizer and air entraining admixture were adjusted.

2.4 Test Methods

(1) Drying shrinkage

Drying shrinkage was measured through the variations in length of 100×100×400mm specimens using dial gauges. Measurements were performed at defined ages of the specimens exposed to air dry conditions (temperature 20±2°C, humidity 65±10%) after water curing during 7 days.

(2) Autogenous shrinkage

The autogenous shrinkage test was conducted with respect to the method proposed by the Autogenous Shrinkage Committee of JCI (2002). The fabrication of the specimens made use of a steel mold of 100×100×400mm perforated with holes at the center of both ends as shown in Fig. 1. Gauge plugs were installed to correspond with the axis of the mold and, a 1mm thick Teflon sheet was disposed on the floor and both ends of the mold to allow free deformations of the specimen. Thereafter, concrete was poured and a polyester film was placed to avoid contact with the air and prevent evaporation and absorption at the surface.

(3) Mock-up test

The mock-up test was carried out on 800×800×800mm specimens. The specimens were treated similarly to the autogenous shrinkage specimens to prevent contact with the air and prevent evaporation and absorption. The specimens were exposed to air dry conditions (temperature 20±2°C, humidity 65±10%) after wet curing during 7 days. Fig. 2 illustrates the disposition of the gauges and thermocouples installed on the specimens.

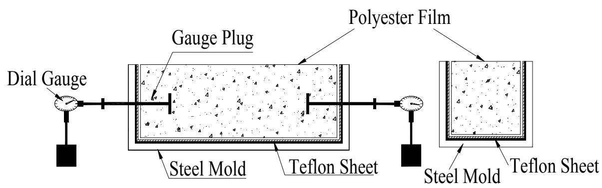


Fig. 1 Set up of autogenous shrinkage test device

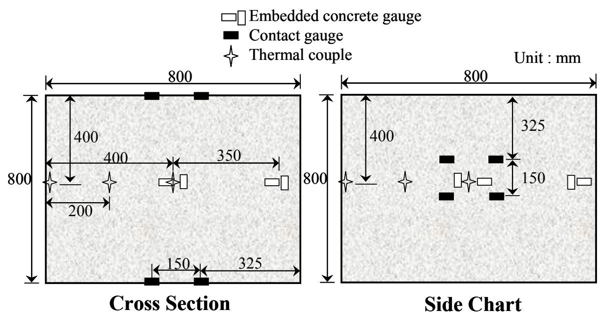


Fig. 2 Specimen for mock-up test

3. TEST RESULTS AND DISCUSSION

3.1 Properties of Fresh Concrete

Table 5 shows the properties of fresh concrete according to the blending of expansive additives and shrinkage reducing agents. It can be seen that the expansive additives has practically no influence on the fluidity and air content. Besides, the use of shrinkage reducing agents degraded the fluidity of concrete and the air content. It seems thus advisable to increase the quantity of superplasticizer and air entraining admixture in order to secure the required fluidity and air content when using shrinkage reducing agents. The setting time tended to shorten by about 6 hours with larger quantities of expansive additives and shrinkage reducing agents.

3.2 Properties of strength

Fig. 3 plots the compressive strengths of concrete at ages 28 days according to the blending ratio of expansive additives and shrinkage reducing agents. The compressive strength of HPC blended with expansive additives increased with the blending ratio until 5% but degraded from a ratio of 7.5%. This can be explained by the fact that the structure of concrete becomes denser according to the generation of the expansible substance that is ettringite until 5% of expansive additives but slackens from a ratio of 7.5% due to the excessive generation of ettringite[2]. It appeared also that the compressive strength degraded with larger blending ratio of shrinkage reducing agents, which can be attributed to the loss of surface tension of void water in the hardened cement following the use of shrinkage reducing agents.

3.3 Properties of Drying Shrinkage

Fig. 4 illustrates the effects of expansive additives and shrinkage reducing agents on the drying shrinkage of HPC. The drying shrinkage strain of EX0.0-SR0.0, the specimen without blending of expansive additives and shrinkage reducing agents reached a relatively large value of 600×10^{-6} at ages 91 days.

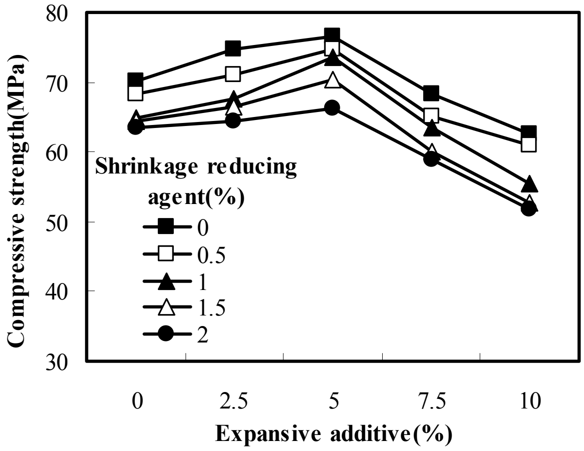
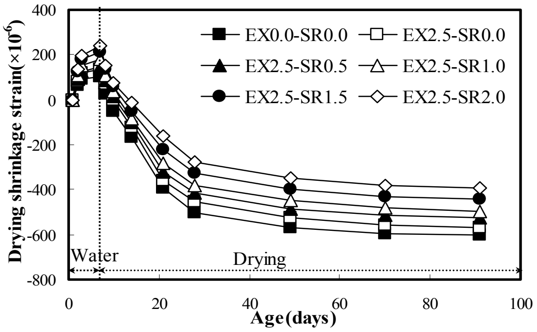


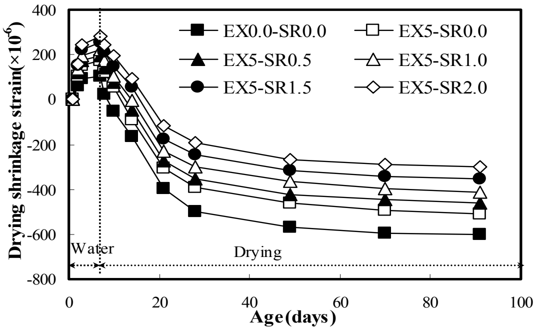
Fig. 3 Compressive strengths at 28 days

Table 5 Properties of fresh concrete

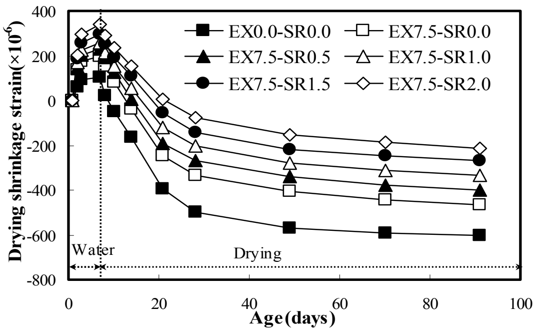
Items / Types	SP (%)	AE (%)	Slump (mm)	Slump flow (mm)	Air content (%)	Setting times(hrs)	
						Initial	Final
EX0.0-SR0.0	1.90	0.040	268	658	4.8	19.92	23.33
EX0.0-SR0.5	1.90	0.030	261	597	4.9	19.08	22.50
EX0.0-SR1.0	1.90	0.025	260	592	5.0	18.17	21.67
EX0.0-SR1.5	2.00	0.020	263	596	5.2	18.00	20.83
EX0.0-SR2.0	2.00	0.015	256	539	4.1	17.67	19.33
EX2.5-SR0.0	1.90	0.040	266	654	5.7	18.20	20.33
EX2.5-SR0.5	1.90	0.030	265	643	6.0	17.37	19.83
EX2.5-SR1.0	1.90	0.025	258	585	5.3	16.25	19.00
EX2.5-SR1.5	2.00	0.015	254	527	4.3	15.37	17.83
EX2.5-SR2.0	2.00	0.010	255	561	3.6	14.68	17.17
EX5.0-SR0.0	1.90	0.040	270	673	4.0	17.53	21.33
EX5.0-SR0.5	1.90	0.023	265	603	5.4	17.03	19.20
EX5.0-SR1.0	2.00	0.018	266	602	4.5	16.75	19.07
EX5.0-SR1.5	2.10	0.012	254	546	4.0	16.27	18.08
EX5.0-SR2.0	2.30	0.012	258	552	3.8	15.83	18.20
EX7.5-SR0.0	1.90	0.040	268	645	5.6	17.27	20.10
EX7.5-SR0.5	2.00	0.020	265	629	4.1	16.83	19.83
EX7.5-SR1.0	2.10	0.018	263	601	4.2	16.07	18.37
EX7.5-SR1.5	2.20	0.015	255	530	3.6	16.13	18.67
EX7.5-SR2.0	2.40	0.015	256	568	4.5	16.53	19.33
EX10-SR0.0	1.90	0.040	270	657	4.0	16.87	18.83
EX10-SR0.5	2.10	0.025	256	587	3.5	16.13	18.23
EX10-SR1.0	2.20	0.025	260	594	4.3	15.83	17.87
EX10-SR1.5	2.30	0.020	249	515	3.5	15.25	17.27
EX10-SR2.0	2.50	0.015	253	524	3.2	15.95	18.03



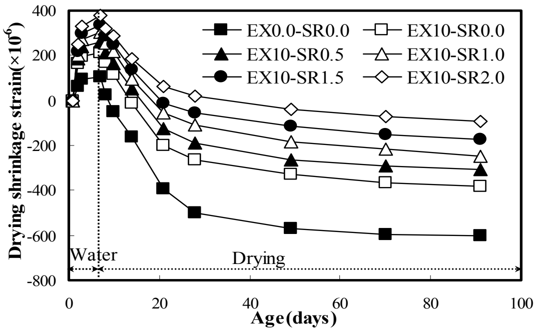
(a) 2.5% of expansive additives



(b) 5.0% of expansive additives



(c) 7.5% of expansive additives



(d) 10.0% of expansive additives

Fig. 4 Effects of expansive additives and shrinkage reducing agents on the drying shrinkage of high performance concrete

In addition, a tendency to expand was also observed due to the generation of ettringite induced by the expansive additives and the absorption of moisture during the period water curing regardless of the blending ratio of expansive additives and shrinkage reducing agent.

The drying shrinkage strain diminished with larger blending ratio of expansive additives in concretes blended with expansive additives. This relationship can be explained by the shrinkage compensation produced by the generation of ettringite and calcium hydroxide that are expansible substances[2, 3]. The same relationship was also observed for concretes blended with shrinkage reducing agents, which is probably due to a physical action degrading the surface tension of the moisture presented inside the voids of the hardened concrete[4].

For concretes blended with a combination of expansive additives and shrinkage reducing agents, remarkable reduction effect on the drying shrinkage could be observed with larger blending ratio of expansive additives and for the same proportion of shrinkage reducing agents. For example, for a ratio of 1% of shrinkage reducing agents, the reduction of drying shrinkage strain at 91 days was seen to improve with drying shrinkage strains of 495×10^{-6}, 410×10^{-6}, 334×10^{-6} and 246×10^{-6} for increasing blending ratios of expansive additives of 2.5%, 5.0%, 7.5% and 10%, respectively.

Fig. 5 describes the effects of expansive additives and shrinkage reducing agents on the drying shrinkage at 91 days according to the type of blending. The combined use of both expansive additives and shrinkage reducing agents is seen to improve the reduction effect on the drying shrinkage by 4 to 25% compared to their individual use regardless of the blending ratios.

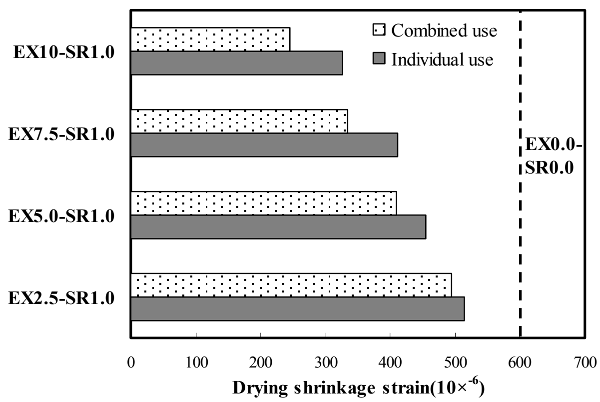
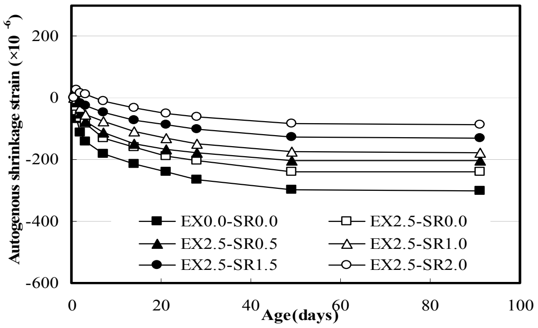


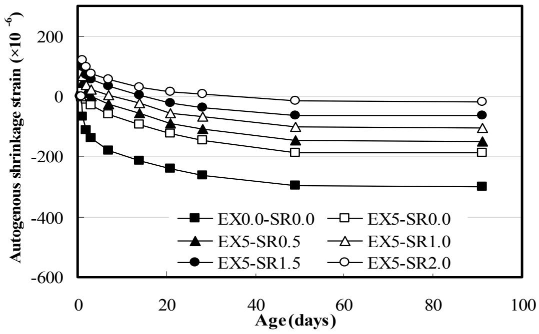
Fig. 5 Effect of expansive additive and shrinkage reducing agent on the drying shrinkage

3.4 Properties of Autogenous Shrinkage

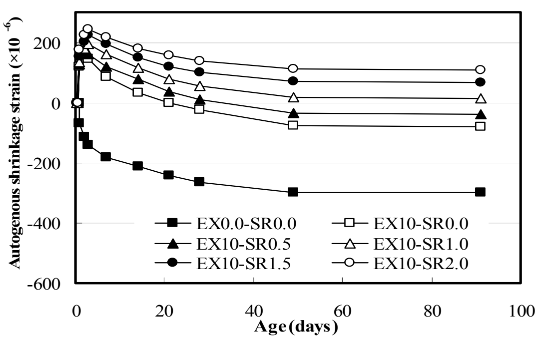
Fig. 6 illustrates the effect of expansive additives and shrinkage reducing agents on the autogenous shrinkage of HPC.



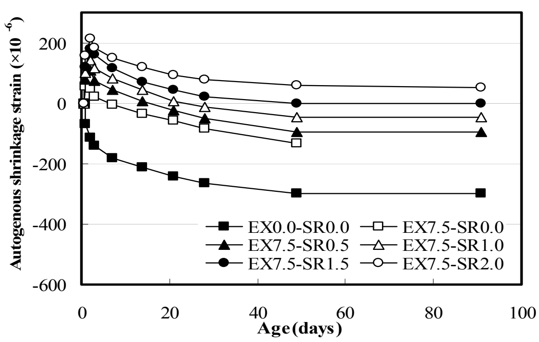
(a) 2.5% of expansive additive



(b) 5.0% of expansive additive



(c) 7.5% of expansive additive



(d) 10.0% of expansive additive

Fig. 6 Effect of expansive additives and shrinkage reducing agents on the autogenous shrinkage of high performance concrete

The autogenous shrinkage strain of EX0.0-SR0.0 reached approximately 301×10^{-6} at 91 days revealing that shrinkage occurred. In addition, similarly to the drying shrinkage, the autogenous shrinkage reduced with larger blending ratios of expansive additives and shrinkage reducing agents. Compared to EX0.0-SR0.0, the autogenous shrinkage decreased by about 74% for blending ratios of expansive additives 10% and about 52% for shrinkage reducing agents 2%.

Similarly to the drying shrinkage, the combined use of expansive additives and shrinkage reducing agent with constant proportion of shrinkage reducing agents also resulted in improving reduction of the autogenous shrinkage with larger ratio of expansive additives. Especially, for the combined use of 7.5% of expansive additives and 2% of shrinkage reducing agents and, the combination of 10% of expansive additives with 1.0%, 1.5% and 2.0% of shrinkage reducing agents, the concrete was in expanded state at 91 days since shrinkage compensation effect due to the use of shrinkage reducing agents appeared to be larger than the autogenous shrinkage.

Fig. 7 describes the effects of expansive additives and shrinkage reducing agents on the autogenous shrinkage at 91 days according to their blending. The combined use of both expansive additives and shrinkage reducing agents is seen to improve significantly the reduction effect on the autogenous shrinkage rather than the individual use of each admixture regardless of their blending ratios.

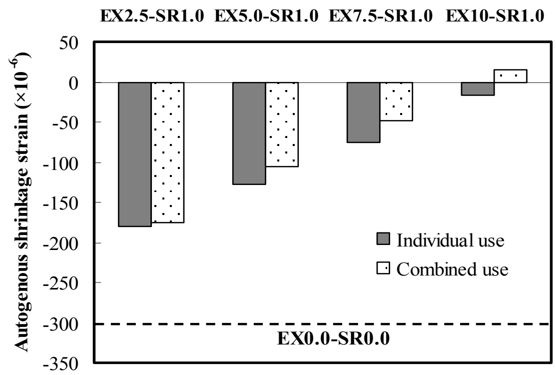
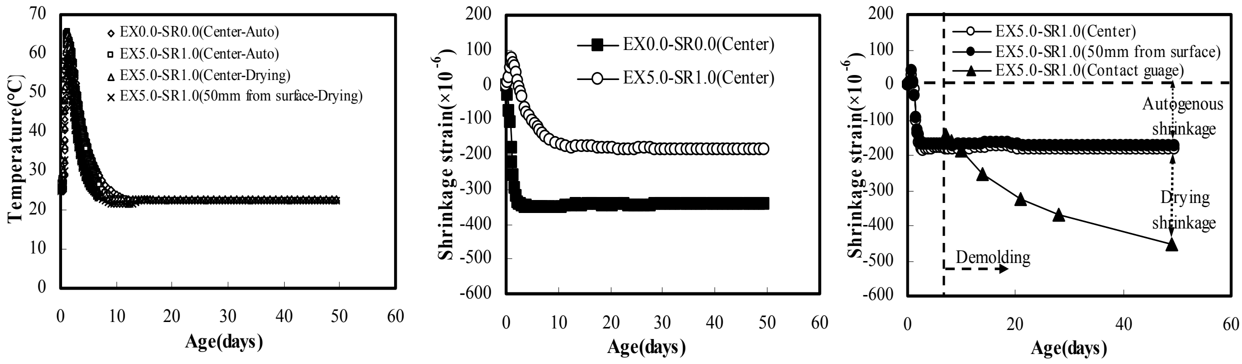


Fig. 7 Effect of expansive additives and shrinkage reducing agents on the autogenous shrinkage

3.5 Results of Mock-Up Test

Fig. 8 plots the results of the mock-up test performed on the mix proportions EX0.0-SR0.0 and EX5.0-SR1.0. The indicated shrinkage strain corresponds to the strain after calibration of the temperature strain due to the hydration heat, taking $10\times10^{-6}/°C$ as the coefficient of thermal expansion for the measured temperature.



(a) Temperature history (b) Autogenous shrinkage (c) Drying shrinkage

Fig. 8 Mock-up test results

As part of the autogenous shrinkage test, the mock-up test performed on EX0.0-SR0.0 resulted in a shrinkage strain of about 350×10^{-6} at 3 days. Thereafter, shrinkage developed smoothly to reach 360×10^{-6} at 49 days. Besides, the shrinkage strain of EX5.0-SR1.0 reached approximately 175×10^{-6} at 49 days, which represents a reduction of shrinkage by about 50% compared to EX0.0-SR0.0 and is nearly identical to the results obtained for the specimens with dimensions of 100×100×400mm.

In the framework of the drying shrinkage test, the mock-up test performed on EX5.0-SR1.0 resulted in a shrinkage strain of about 170×10^{-6} at 49 days at the center of the specimen. This result shows no difference with the autogenous shrinkage specimen. Even if the autogenous and drying shrinkages can be considered inside this specimen, it is presumed that drying shrinkage did not occur actually inside the specimen. The investigation of Larrad et al.[5] on the diffusion of moisture inside a HPC specimen (thickness 160mm) reported that the diffusion of moisture occurs only from the surface down to a depth of 20mm at ages 3 months. Accordingly, this study also assumes that diffusion of moisture did not practically occur at the section of the gauge embedded at a depth of 50mm from the surface of the specimen. Moreover, after stripping of the mould, the whole shrinkage strain measured by the contact gauges was about 460×10^{-6}, which is larger by 260×10^{-6} approximately than the shrinkage strain inside the specimen.

5. CONCLUSIONS

(1) The expansive additives and shrinkage reducing agents were producing remarkable shrinkage reduction effect on HPC. Especially, the combined use of expansive additive and shrinkage reducing agent was seen to enhance the shrinkage reduction effect compared to the individual use of both admixtures.

(2) The combination of 5% expansive additives and 1% shrinkage reducing agents was seen to have no bad influence on the workability and strength as well as to reduce shrinkage by about 50%.

(3) The combination of 5% expansive additives and 1% shrinkage reducing agents was also verified to reduce shrinkage by approximately 50% in the mock-up tests. However, the surface-dry effect resulted in a total shrinkage strain at the surface larger by 260×10^{-6} compared to the shrinkage inside the specimen.

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