Proc. Schl. Eng. Tokai Univ., Ser. E
38 (2013) 25-32

Influence of a Shrinkage Reducing Admixture on the Properties of Ultra High-Strength Concrete and Mortar

by

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(Received on Mar. 30, 2013 and accepted on May. 16, 2013)

Abstract

In this study, influence of a shrinkage reducing admixture (here in after "ASA") on various properties of ultra high-strength concrete and mortar were investigated. A dosing method of a designated amount of ASA, added to mixing water and replaced with the same amount of mixing water were adopted.

As the results, an effect of dosing ASA on the autogeneous shrinkage reduction was observed especially in the early stage and no significant influence on the freezing and thawing resistance by dosing ASA was observed in this experiment. It was confirmed that the difference of dosing method of ASA influences both the fresh and mechanical properties of mortar and concrete.

Keywords: Shrinkage Reducing Admixture, Autogeneous Shrinkage, Freezing and Thawing, Replace, Addition

1. Introduction

Demand for the high strength concrete is increasing associated with the requirements for taller building and longer span structures. In 2006, Architectural Institute of Japan specified a standard "The design and control of shrinkage cracking of reinforced concrete building construction" where the permissible drying shrinkage of concrete is specified to be equal to or less than 800×10^{-6} to promote the practice of high-strength concrete constructions without dangerous cracks. However, ultra high-strength concrete with a design compressive strength of 100N/mm^2 undergoes considerable autogenous shrinkage strain and the resulting cracks are of major concern[1)]. Shrinkage reducing admixture (ASA)[2)] is an admixture capable of reducing shrinkage strain but has some adverse effects such as loss of strength and resistance to freezing and thawing and unknown factors in effectiveness at lower water-cement ratios. In addition, unlike the usual admixture, ASA used in this study contains no water, hence the impact on the properties of concrete may differ substantially by dosage method (exclusive or inclusive mix). In this study, properties of the ultra high-strength concrete and mortar with a low-water ratio were studied when ASA is dosed with exclusive or inclusive mix.

Table.1 Material

Material	Type	Symbol	Properties and Component
Cement	Taiheiyō cement, Silica fume cement	C	Density : $3.06\ \text{g/cm}^3$
Fine aggregate	Ōigawa product	S	Density : $2.59\ \text{g/m}^3$: Fineness modulus 2.42
Coarse aggregate	Oume product	G	Density : $2.70\ \text{g/m}^3$:Maximum size 20 mm
Admixtures	High-range water reducing agent	SP	Polycarboxylic acid compound solid content 36 %
	Anti Shrinkage Agent	ASA	polyalkylene glycol derivative
	Antifoaming agent	—	Alcohol system antifoaming agent

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Table.2 Mix proportion of mortar and concrete

Mix proportion No.		W/C	Unit Content (kg/m^3)				SP	ASA	Antifoaming agent
		(%)	W	C	S	G	(Cx%)	(Cx%)	(Cx%)
series Ⅰ	①	13	209	1606	690	−	1.000	0	0.05
	②(Rep.)						0.985	0.7	
	③(Rep.)						0.950	1.4	
	④(Rep.)						0.930	2.1	
	⑤(Add.)						0.950	0.7	
	⑥(Add.)						0.825	1.4	
	⑦(Add.)						0.750	2.1	
series Ⅱ	⑧	13	209	1606	690	−	0.950	0	0.05
	⑨(Rep.)							0.7	
	⑩(Rep.)							1.4	
	⑪(Rep.)							2.1	
	⑫(Add.)							0.7	
	⑬(Add.)							1.4	
	⑭(Add.)							2.1	
series Ⅲ	⑮	13	155	1192	513	613	1.000	0	0.05
	⑯(Rep.)						0.975	0.7	
	⑰(Rep.)						0.950	1.4	
	⑱(Rep.)						0.935	2.1	
	⑲(Add.)						0.950	0.7	
	⑳(Add.)						0.900	1.4	
	㉑(Add.)						0.825	2.1	
series Ⅳ	㉒	12	160	1333	291	707	1.100	0	0
	㉓(Rep.)						1.100	0.53	
	㉔		120	1000	407	989	1.250	0	
	㉕(Rep.)						1.200	0.7	

2. Materials and experiments

On the practical application of ultra high strength concrete, the influences of ASA on mortar and concrete need to be clarified. In this study, ASA was added to the ultra high strength concrete and examined the fresh properties such as slump flow (hereafter denoted as SF), air content, setting time, flow rate and surface tension, and hardened properties such as compressive strength, autogenous shrinkage strain, freezing and thawing resistance and hydration rate.

Materials used are shown in Table 1 and mix proportions are shown in Table 2. Mix names with “Rep.” and “Add.” denote inclusive mix and exclusive mix where ASA was mixed as a part of unit water or as an add-on to the unit water respectively. The other admixtures were used as an inclusive mix. Cement used was commercial silica fume premixed cement and the crushed fine and coarse aggregates were from the Ooigawa River and Oume. Mortars of experiment series I were proportioned with a constant dosage of superplasticizer (SP) and those of series II were controlled to have a constant slump flow (SF) while series Ⅲ (SF) were controlled to have a constant SF and those of series Ⅳ were with different mix proportions.

Mixing of mortar was performed with the fine aggregate and cement introduced first in the Hobart type mortar mixer. After 15 seconds of dry mixing, water with admixture was mixed for 30 seconds with a low speed, 90 seconds with a mid-speed and high-speed for 160 seconds, finished.The total mixing time was 3 minutes.

SF, mini slump flow (MSF) and air content were measured for all the mixes and setting test, flow rate, compressive strength test, and ignition loss were performed using the series I mortar in Table 2. Freezing and thawing test was done with the seriesⅢconcrete and autogenous shrinkage strain was measured with the series I mortar and the seriesⅣconcrete.

The test items and method of this experiment are shown in Table 3, and details of the mold of autogenous shrinkage strain test are shown in Figure 1. A mini slump cone with a height of 15 cm, top diameter of 5 cm and bottom diameter of 10 cm was used for the SF testing of mortar. Flow rate was determined by measuring the passage time through the inscribed circles of a diameter of 200 mm and 250 mm on the slump board as a viscosity index. Three specimens with a diameter of 50 mm and a height of 100 mm were prepared per mix for the 28-day compressive strength test. Two prism specimen with a 100x100x400 mm dimensions were subjected to autogenous shrinkage measurement of concrete, while those with a 40x40x160 mm dimensions were for autogenous shrinkage measurement of mortar. The specimens underwent a simple sealed curing wrapped with a polyester film and then measured with a non-contact laser displacement mater. After setting, the markers for the contact gauge were attached on the specimen sealed with an aluminum adhesive tape and the measurement was performed with a contact gauge method. Two prism specimens per each mix with dimensions of 100x100x400 mm were subjected to freezing and thawing test. The ignition loss test was performed according to Uematsu3). When specimens become a specified age, they were crushed with a hammer and immersed in acetone under vacuum to suspend hydration. Then the specimens were put into a 110 ℃ furnace for 24 hours. After cooling down in a desiccator, the sample was powdered using a mortar, weighed in a precision of 1.0 g in a crucible and heated up to 975 ℃ in the furnace to dehydrate the bound water. After the heating of 1 hour, the crucible was cooled within the desiccator and loss of mass was measured. Subtracting the ignition loss of the cement itself from the total mass loss yielded the quantity of bound water.

Table.3 Test conditions

Test & Measurement	Test Method	Curing method	Measurement environment
Slump Flow	JIS A 1150	—	temperature 20 ºC
Air content	Mortar JIS A 1118		
	Concrete JIS A 1129		
Setting time	JIS A 1147		
Surface Tension	Denuce' surface tension test		
Drift Velocity	Slump plate measurement		
Compressive Strength	JIS A 1108	Sealed for three days after that underwater.	temperature 20 ºC Humidity 70 % Water temperature 20 ºC
Ignition loss	Paper of Uematsu		
Freezing and Thawing	JIS A 1148		
Autogenous Shrinkage Strain	JCI-SAS2-2	Sealed	temperature 20 ºC Water temperature 20 ºC

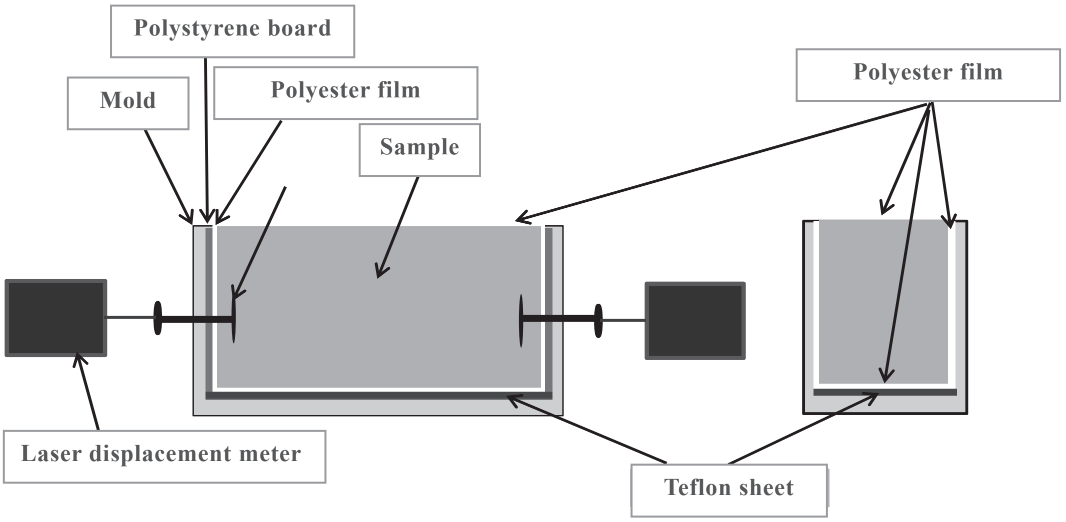

Fig.1 Details of a mold

3. Results and discussions

3.1 Fresh Behavior

Relationships between amount of ASA and slump flow are shown in figure 2 and those of ASA and setting time are shown in figure 3. Mini slump flow of fresh mortar and the test result of air content are shown in table 4. As shown in figure 2, MSF became large with an increase in the amounts of ASA, and when the mix was exclusive rather than inclusive. Moreover, air content showed a slight decrease in proportional to the amount of ASA. Setting became delayed with an increase in the amounts of ASA as shown in figs. 3 and 4, where the delay was considerable in the inclusive mix while slight in the exclusive mix, probably because the dosage of SP became relatively small when ASA was admixed as the exclusive mix rather than inclusive mix at the constant flow value (see table).

Relationship between amount of ASA and flow rate is shown in figure 5. The numerical value in the figure is the total moisture content by volume of mortar in m³ including ASA as a moisture in each mix proportion. When the ASA was added as the inclusive mix, flow rate decreased slightly but it increased when ASA was added as the exclusive mix. It is likely that the influence of ASA on the flow rate was small while that of moisture in mortar was significant.

The relation between dosage of ASA and surface tension is shown in figure 6 where surface tension decreases with the dosage of ASA, while at the dosage exceeding 0.7%, surface tension remained unchanged.

Table.4 Result of fresh properties

Mix proportion No.	MSF, SF (mm)	Air (%)	Temperature (ºC)
①	305×305	4.3	29
②(Rep.)	310×310	3.6	29
③(Rep.)	315×310	3.5	29
④(Rep.)	330×330	3.1	29
⑤(Add.)	315×310	3.5	29
⑥(Add.)	315×310	3.4	29
⑦(Add.)	320×315	3.6	29
⑧	210×210	3.9	29
⑨(Rep.)	275×275	3.7	29
⑩(Rep.)	315×310	3.3	29
⑪(Rep.)	330×330	3.1	29
⑫(Add.)	315×310	3.5	29
⑬(Add.)	390×385	3.4	29
⑭(Add.)	460×450	3.2	29
⑮	690×680	2.0	27
⑯(Rep.)	660×660	2.2	26
⑰(Rep.)	670×670	1.7	26
⑱(Rep.)	650×650	2.0	27
⑲(Add.)	750×750	2.3	26
⑳(Add.)	730×730	2.2	26
㉑(Add.)	710×710	2.0	27
㉒	660×710	3.3	22
㉓(Rep.)	750×780	1.6	22
㉔	680×710	3.5	20
㉕(Rep.)	690×710	2.1	21

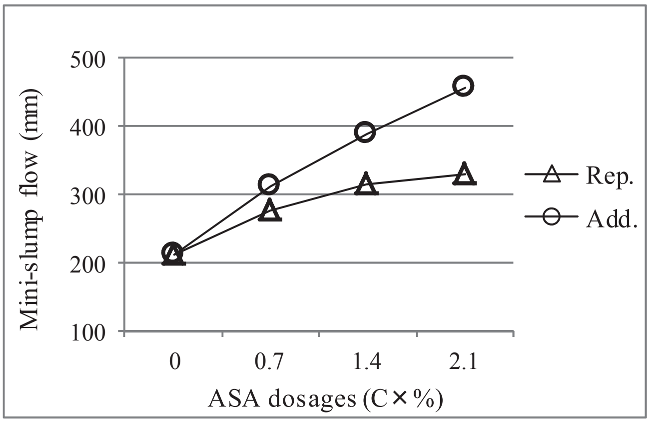

Fig.2 Influence of dosing method on slump flow

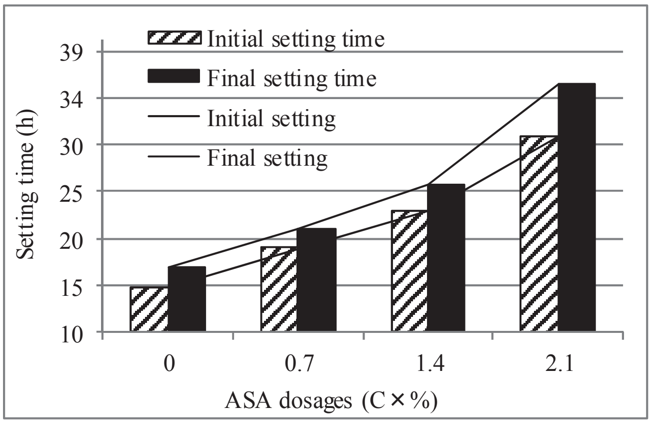

Fig.3 Relationship between ASA dosages and setting time (Rep.)

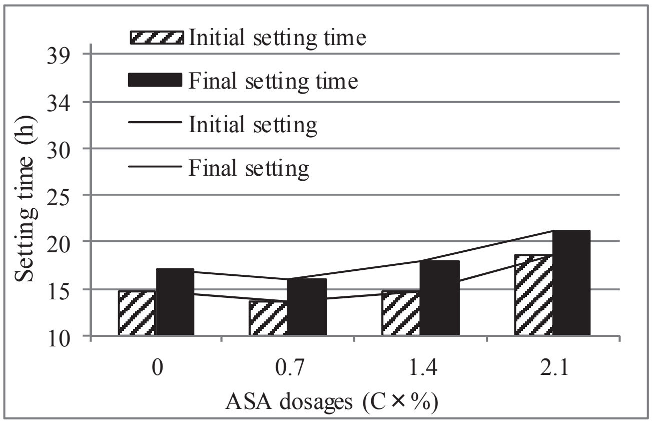

Fig.4 Relationship between ASA dosages and setting time (Add.)

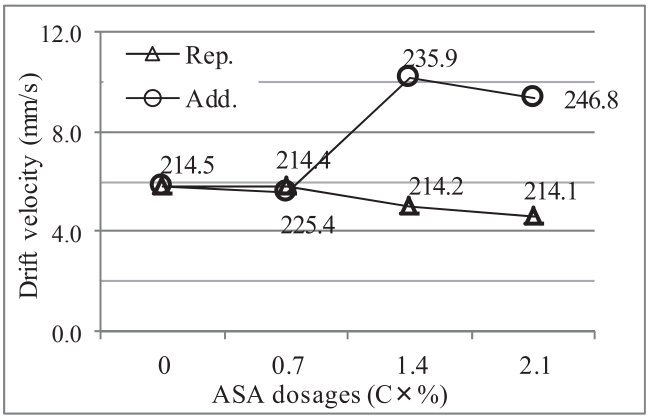

Fig.5 Relationship between ASA dosages and drift velocity

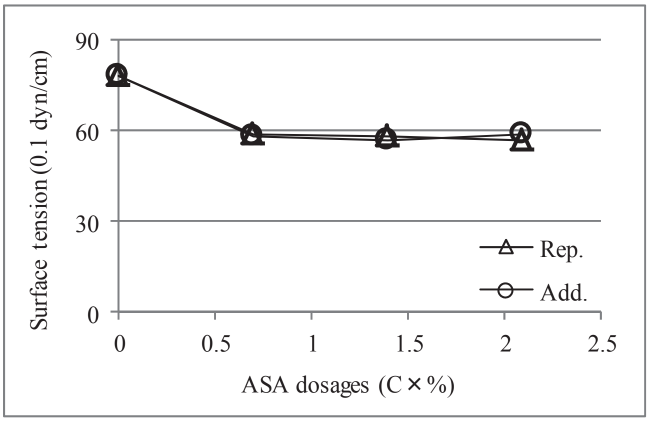

Fig.6 Relationship between ASA dosages and surface tension of water

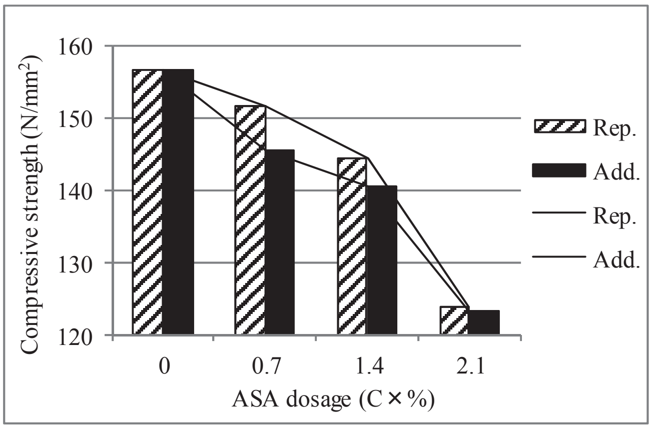

Fig.7 Relationship between ASA dosages and compressive strength

3.2 *Hardened Properties*

Relationship between amount of ASA and 28-day compressive strength is shown in figure 7. The 28-day strength decreased as the amounts of ASA increased. The decrease in strength was more notable when ASA was added as exclusive mix rather than added as inclusive mix. The decrease in compressive strength was approx. 5%. This is because the actual W/C of the mix became small at the inclusive mix compared with that of the exclusive mix.

Autogenous shrinkage of mortar and concrete specimens are shown in figures 8 and 9. Shrinkage reduction rate on the basis of the plain mortar at the age of 90 days was shown in figure 10. Autogenous shrinkage strain of mortar decreased with an increase in the dosage of ASA. On the basis of ASA=0%, the shrinkage reduction rate was 5% at ASA=0.7, 30～35% at ASA=1.4% and 45～55% at ASA=2.1%. It is shown that ASA demonstrates the shrinkage reduction most effectively at from o.5 days to 3 days, and it is ineffective after 3 days as the difference of length change was very small at later ages. Moreover, the difference in the amount of shrinkage by inclusive or exclusive mix was small at later ages. Generally the mechanism of shrinkage can be explained by the capillary tension theory.

$$\Delta P=\gamma\,(1/r_1+1/r_2)$$

where, ΔP : capillary tension（N/m2）, γ : surface tension of liquid（mN/m）,
r_1, r_2 : principal radius of curvature at the liquid-gas interface（mm）showing that the capillary tension is proportional to the surface tension of liquid.

However, as seen in figure 6 and figure 8, the shrinkage reduction increased with the dosage of ASA, while surface tension no more changes at an ASA dosage more than 0.7%. This shows that the shrinkage reduction effect has to be attributed to certain unknown factors other than surface tension in this experiment. Also in the case of concrete, the shrinkage reduction effect by ASA was confirmed and autogenous shrinkage strain was reconfirmed to become small with an increase in unit amount of coarse aggregate.

The relationships between number of freeze/thaw cycle and dynamic elastic modulus and the mass loss are shown in figure 11and figure 12. It is observed that the freezing and thawing resistance was not affected by the mix proportion and the dosage of ASA in this experiment. Similarly the dosage of ASA did not affect the mass loss during freeze/thaw cycles. These results can be considered as the consequence of extremely low water permeability of the matrix due to low water binder ratio.

The amount of bound water by the dosage of ASA on the basis of that with ASA=0% is shown in figure 13 and figure 14. In the material age of 3 days, both in exclusive and inclusive mix, the amount of bound water became small with an increase in dosage of ASA. Specimens with the inclusive mix, the difference in the amount of bound water with respect to that without ASA became small and almost equal at the age of 56 days. However, those with exclusive mix, the amount of bound water increased with an increase in the dosage of ASA with ages. It is supposed that moisture content in the mortar was high due to the exclusive mix and the amount of bound water became large accordingly with an increase in the dosage of ASA.

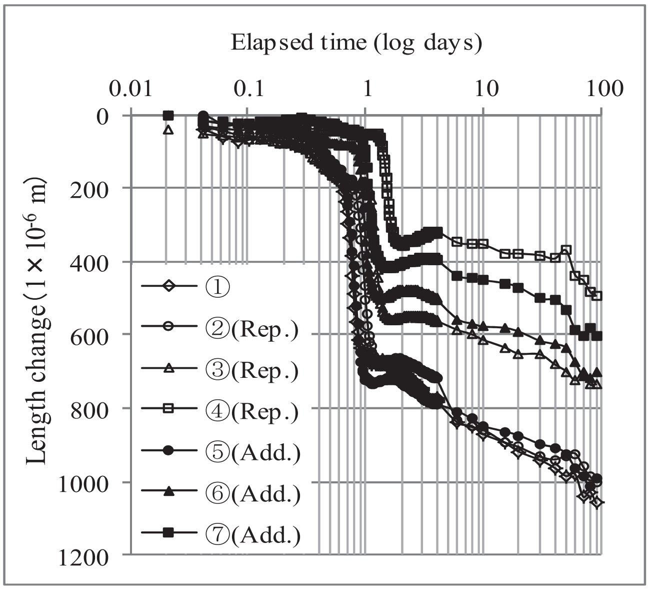

Fig.8 Autogenous shrinkage of mortar

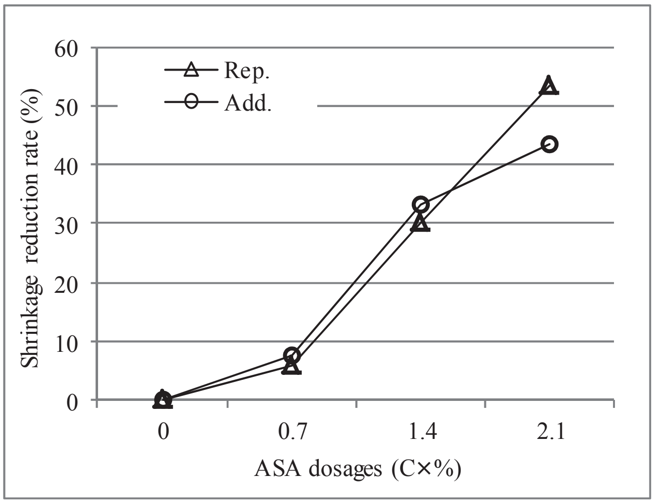

Fig.10 Relationship between ASA dosages and shrinkage reduction rate

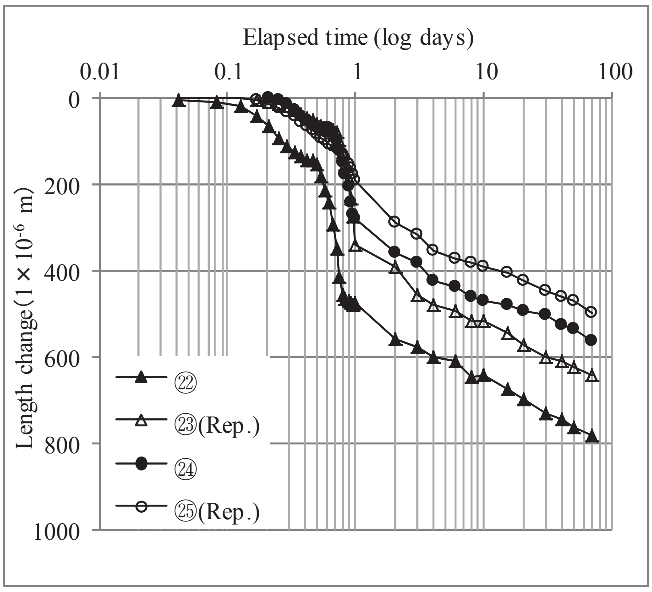

Fig.9 Autogenous shrinkage of concrete

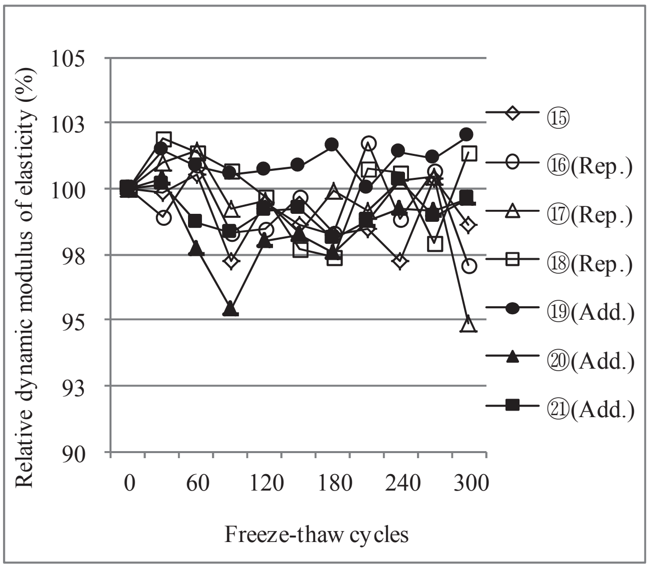

Fig.11 Influence of dosing method on freeze-thaw resistance

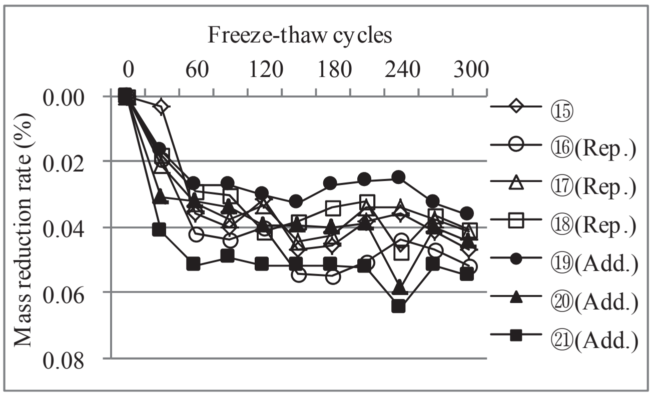

Fig.12 Influence of dosing method on mass reduction rate

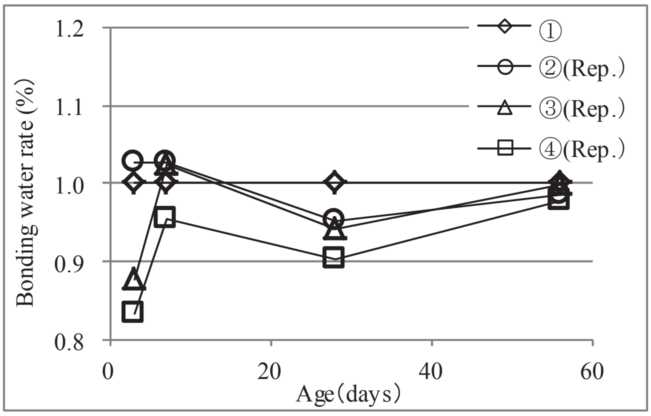

Fig.13 Relationship between bonding water and ASA dosages (Rep.)

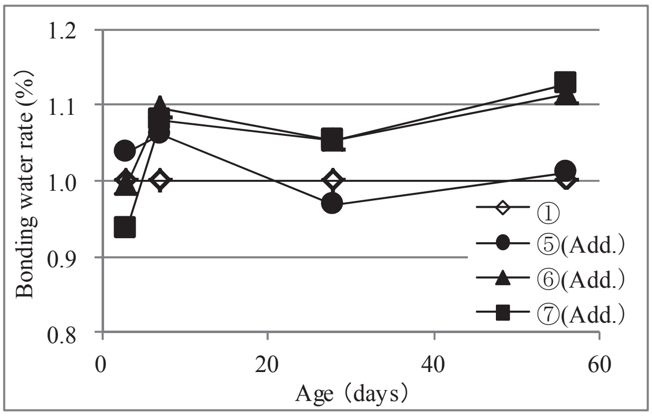

Fig.14 Relationship between bonding water and ASA dosages (Add.)

4. Conclusions

1) With an increase in the dosage of ASA, air content decreased slightly, mini slump flow increased and the setting time was delayed, while the influence of the ASA on the flow rate was small and the moisture content in mortar serves as a predominant factor.

2) With an increase in the dosage of ASA, compressive strength decreased more significantly at the exclusive mix than at inclusive mix.

3) In the low-W/C mortar, ASA posed an effect on reduction of autogenous shrinkage reducing approx. 50% at a dosage of 2.1%. In this experiment, the reduction of autogenous shrinkage was attributed to certain unknown factors other than surface tension. ASA was also effective in the low-W/C concretes and the autogenous shrinkage strain was reconfirmed to become small with an increase in the unit amount of coarse aggregate.

4) In the low W/C concrete with less air content, the reduction of freezing and thawing resistance was not observed even at a high dosage of ASA.

5) Hydration reaction was delayed at early ages with an increase in the dosage of ASA, while the difference in the hydration degree was mitigated with ages.

5. References

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