STUDY ON THE IMPROVED DURABILITY OF CONCRETE USING THE C-S-H BASED HARDENING ACCELERATOR

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ABSTRACT

In recent years, a C-S-H based hardening accelerator having a completely different mechanism from the conventional hardening accelerator has been developed and research is proceeding. The reason why hardening is promoted by the C-S-H based hardening accelerator that C-S-H nanoparticles which are the main components of C-S-H based hardening accelerator faster than C-S-H formed by cement in usually. According to the past studies, progress of compressive strength at early age and long term by steam hardening, and the low water-cement ratio is confirmed by using the C-S-H based hardening accelerator. On the other hand, there are few studies assuming all field applications. In this paper we assume the case of using water cement ratio 50% used in general civil engineering construction sites in Japan. In this study, we suppose that the C-S-H based hardening accelerator will densify the voids in concrete and will improve compressive strength and durability. Based on the additional method of the C-S-H based hardening accelerator proposed by the past research, we investigated the additional method of the C-S-H based hardening accelerator which works effectively on various water cement ratio and examined to evaluate the durability. As a result, the additional amount of the C-S-H based hardening accelerator constant with respect to the amount of water, even at high water cement ratio, the same effect as low water cement ratio could be expected. Although no significant difference was observed in compressive strength and void depending on with or without the C-S-H based hardening accelerator mix proportion. From the results of the air permeability test, concrete tended to be densified by any additional method.

Keywords: C-S-H based hardening accelerator, concrete, water cement ratio, durability.

1. INTRODUCTION

The safe use of the structure depends on the durability of the structure such as the degree of deterioration. As carbonation of concrete increases, the resistance decreases as the number of voids increases. Thus, the durability depends on the air gap. The voids in the concrete decrease as the cement hydration reaction progresses. Initially, there is a method of using a hardening accelerator in a method of promoting a hydration reaction. In recent years, a new hardening accelerator, C-S-H based hardening accelerator has been developed. Conventional hardening accelerators directly promoted the hydration reaction of cement. However, The C-S-H based hardening accelerator accelerates the hardening by C-S-H nanoparticles as the main component promoting the formation of hydrates. The authors considered that this mechanism makes the voids in the concrete denser and improves compressive strength and durability. Since the mechanism is largely different from conventional hardening accelerators, investigation from all angles is required. In the past studies using the C-S-H based hardening accelerator, it has been confirmed that the initial strength is developed and the long-term strength is exhibited at the steam curing, the standard curing, and the low water cement ratio. On the other hand, there are few studies assuming all the application on the site. In this paper, we assumed the use of W/C of about 50% used in construction site of general Japanese civil engineering. As an example of applying a hardening accelerator to a concrete structure, it is a mountain tunnel. Construction cycle is one cycle of construction every 2days including implantation and curing. As an advantage of advancing the installation cycle, it is possible to shorten the construction period and suppress the personnel expenses.

In this research, it was aimed to grasp the relationship between C-S-H based hardening accelerator and durability assuming use of C-S-H based hardening accelerator at W/C50%. The cement type, water cement ratio and curing were changed, and the curing properties, hydration characteristics and substance permeability were experimentally measured.

Table 1: Types and physical properties of materials

material	symbol	Types and physical properties
Water	W	Tap water
Cement	OPC	Ordinary Portland cement (density 3.16g/cm^3)
	BFS	Blast furnace slag fine powder (density 2.91g/cm^3)
Fine aggregate	S	Mountain sand (density 2.62g/cm^3)
Coarse aggregate	G1	Limestone (density 2.70g/cm^3)
	G2	Crushed stone (density 2.71g/cm^3)
Admixture	SP	High performance AE water reducing agent (polycarboxylic acid ether type compound)
	AE	AE agent (alkyl ether compound)
	ACX	C-S-H based hardening accelerator (C-S-H nanoparticle)

Table 2: Mortar mix proportion

symbol	Cement type	ACX amount to use(%)	Unit Amount(kg/cm^3) W	OPC	BFS	S
N-0	N	0	225	450	0	1350
N-2		2				
BB-0	BB	0		225	225	
BB-2		2				
BC-0	BC	0		135	315	
BC-2		2				

Table 3: Concrete mix proportion

symbol	Cement type	ACX amount to use(%)	W/C (%)	s/a (%)	Unit Amount(kg/m^3) W	OPC	BFS	S	G
N-0	N	0	50	48	170	340	0	839	955
N-2		2							
BB-0	BB	0			170	170	170	833	948
BB-2		2							
BC-0	BC	0			165	99	231	861	954
BC-2		2							

2. STRENGTH DEVELOPMENT IN VARIOUS CEMENTS

2.1. Outline of test

Change the cement and confirm strength development of mortar and concrete at W / C 50%. Mortar and concrete with W/C50% were made. **Table 1** shows types and physical properties of materials. Three types of cement were prepared ordinary portland cement (OPC), BB with 50% blast furnace slag fine powder replaced for OPC, and BC replaced with 70%. As shown in **Table 2,** the mortar was prepared according to the JIS (Japanese Industrial Standard) based plan mix proportion. Concrete was prepared according to the plan mix proportion shown in **Table 3**. All of the prepared specimens were cured with a constant temperature and humidity chamber (temperature: 20℃, relative humidity: RH60%). A compressive strength test was performed at a predetermined age. In addition, in order to examine the strength development due to the temperature, strength development was examined by changing the curing temperature in the mortar test by the same mix proportion as BB in **Table 2**. Temperature was set at 20, 40 and 60℃, and strength development in mortar with no addition and C×4% was measured.

2.2. Strength development result of mortar

Figure 1 shows the expression of compressive strength depending on the presence or absence of addition of a hardening accelerator using various cements. In any of the cements, the promotion effect of the strength development in the case of adding the curing accelerator did not appear remarkably.

2.3. Strength development results of concrete

Figure 2 shows the strength development by the presence or absence of the hardening accelerator by concrete. Although it seems to be strengthening although it is slight, it was not a big difference.

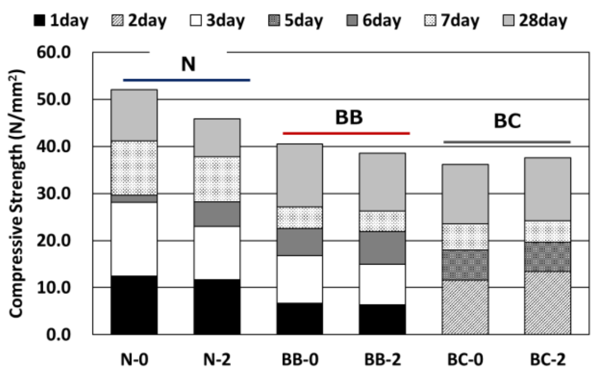

Figure 1: Strength development result of mortar

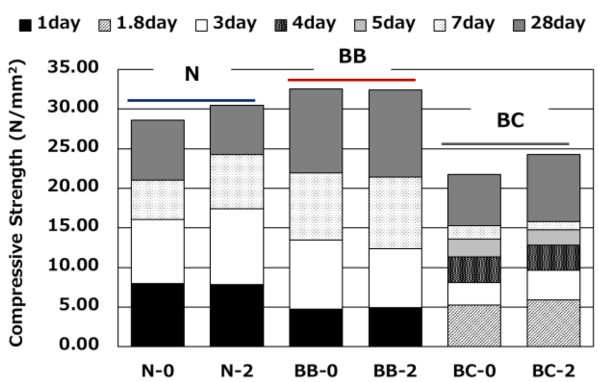

Figure 2: Strength development results of concrete

3. STRENGTH DEVELOPMENT AT CONSTANT CONCENTRATION IN UNIT WATER AMOUNT

3.1. Outline of test

As described above, in the case of C×2% and C×4% which are ordinarily added amounts, the strength development by the C-S-H based hardening accelerator at the high water cement ratio could not be confirmed. Therefore, we focused on the hardening promotion mechanism of the C-S-H based hardening accelerator. In the mechanism, ions eluted from the cement and C-S-H nanoparticles act to accelerate hardening. Therefore, we considered that it is necessary not to add to the mass of cement like the usual admixture, but to keep constant the concentration in the unit water. Based on the concentration of W/C40%, the amount of 4% added to the mass of cement (C×4%). Concrete in which the unit water amount was fixed at 170 kg/m^3 and the water cement ratio was varied to 40, 60, 70% was made in order to make the addition amounts of the C-S-H based hardening accelerator in the plan mix proportion of **Table 3**. The mix proportion is shown in **Table 4**. A total of three patterns of C-S-H type hardening promotion added W×10%, ordinary added amount C×4% addition, no addition ACX0% were prepared. A compressive strength test according to JIS was carried out. The specimens were sealed and cured at constant temperature and humidity (20℃,RH60%). Molds were removed at age of 1, 3, 7 and 28days and used for compressive strength test.

3.2. Strength development result at constant concentration in unit water amount

The test results of compressive strength are shown in **Figure 3**. As can be seen from the figure, when added at C×4% at W/C60%, strength development due to the addition of C-S-H based hardening accelerator could not be confirmed significantly as compared with ACX0%. Likewise, even at W/C70%, strength development due to the addition of the C-S-H based hardening accelerator is not noticeable. On the other hand, C-S-H based hardening accelerator W×10% was added, strength development was confirmed in all W/C. **Table 5** shows the rate of increase in compressive strength with reference to the strength of ACX0%. From the above results, when the C-S-H based hardening accelerator is added in proportion to the mass of cement, no strength development is observed at the high water cement ratio. However, when added at a constant ratio to the unit water amount, the strength development of the C-S-H based hardening accelerator could be confirmed at the same rate in all water cement ratios. Therefore, we investigated the durability by the C-S-H based hardening accelerator.

4. DURABILITY UNDER CONSTANT CONCENTRATION IN UNIT WATER AMOUNT

4.1. Outline of test

As a durability test, an air permeability test and a carbonation promotion test were carried out in order to examine the ease of passing through the gas. The easiness of passing through water was

Table 4: Concrete mix proportion

W/C (%)	s/a (%)	air (%)	Unit Amount(kg/m³)					Admixture		ACX	
			W	OPC	BFS	S	G	SP(%)	AE	Amount to use(%)	Addition amount(g)
40	44	4.5	170	213	213	743	975	0.4	4.5A	0	-
								0.3	2.5A	C×4	17.0
								0.3	2.5A	W×10	17.0
60	48			142	142	870	971	0.4	3.5A	0	-
								0.3	4.5A	C×4	11.4
								0.3	5.0A	W×10	17.0
70	50			121	121	923	952	0.3	4.25A	0	-
								0.3	5.5A	C×4	9.7
								0.3	6.0A	W×10	17.0

Table 5: Rate of increase in compressive strength with reference to the strength of ACX0%

day	W/C40%			W/C60%			W/C70%		
	ACX0%	C×4%	W×10%	ACX0%	C×4%	W×10%	ACX0%	C×4%	W×10%
1	100	124	124	100	97	124	100	95	118
3	100	116	116	100	104	121	100	109	116
7	100	114	114	100	95	119	100	110	119
28	100	115	115	100	95	117	100	-	-

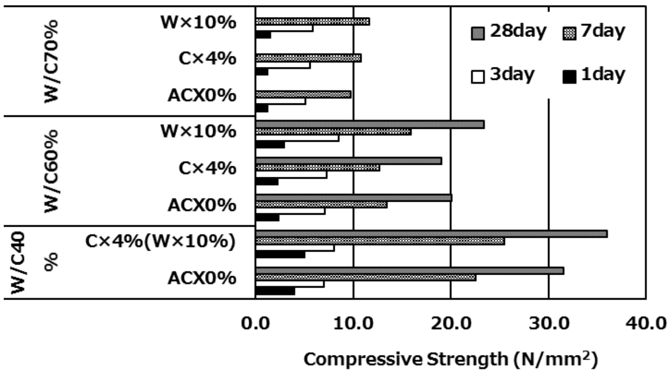

Figure 3: Strength development results of concrete

also examined by a simple permeability test and a vacuum water absorption test. Concrete was done with W/C 40, 60% in **Table 3** of Chapter 3.

4.1.1. Air permeability test

For the specimen, a cylinder specimen of φ100×50 mm was prepared, sealed hardening was carried out with constant temperature and humidity (20℃, RH60%), and the mold was removed at age (7, 28days). In order to remove moisture contained in the voids, the specimen was allowed to stand in a drying oven at 40℃ until reaching a constant weight. The purpose of setting at 40℃ is to avoid removing bound water in concrete. Air permeability was calculated from the test results, and the air permeability coefficient was calculated using the equation.

4.1.2. Vacuum water absorption test

A specimen of φ100 ×50mm was prepared as a specimen. The specimens were sealed and cured at constant temperature and humidity (20℃,RH60%). The mold was removed at age (7, 28days). It was allowed to stand for 2 weeks in a drying oven and dried. After that, the side was protected with aluminum tape to prevent water absorption from the side of the specimen. Water was poured so that it could be dipped from the bottom of the specimen up to 2.5cm, sucked for 1 hour with a vacuum pump, and kept in a vacuum state for 2hours. After the end of water absorption, the specimen was split. Seven points of moisture absorption were measured, and the average value was taken as the water absorption depth.

4.1.3. Simple permeability test

An outline of the simple permeability test is shown in **Figure 4**. Specimens of 150×150×150mm were prepared as specimens. The specimens were cured by sealing at constant temperature and humidity (20℃,RH60%). The mold was removed at age (7, 28days).

Thereafter, it was allowed to stand in a constant temperature and humidity chamber until the concrete surface water ratio reached 4.5%. Next, it was transferred to an aerial environment and a simple permeability test was installed on the side surface and sealed. We measured the amount of moisture reduction every hour for up to 12hours. In order to maintain the pressure in the same state, water was injected up to the maximum amount of 20ml for each measurement. 7days age was measured up to 24hours, and 28days old up to 72hours.

4.2. Durability measurement result

4.2.1. Air permeability test

The results of the air permeability test are shown in **Figure 5**. The figure shows that the air permeability coefficient decreases in both W/C40% and 60% compared with ACX0%. It was found that the air permeability coefficient decreased by adding the hardening accelerator regardless of the addition amount of the C-S-H based hardening accelerator. In addition, the effect of improving the air permeability was large for W/C60%, which has a larger void volume than the W/C40% with a dense void structure. Therefore, it was found that adding a C-S-H based hardening accelerator to a high water cement ratio densifies the void and makes air permeability less likely.

4.2.2. Vacuum water absorption test

Figure 6 shows the results of the vacuum water absorption test. Compared to ACX0%, a decrease in water absorption depth was observed by adding a hardening accelerator regardless of the addition amount of the C-S-H based hardening accelerator. When the original void structure is dense W/C of about 40%, the effect of addition is small, it can be seen that the addition of ACX greatly reduces the water absorption depth but at W/C60%. This shows the same trend as the result of the air permeability test.

4.2.3. Simple permeability test

The test results of the simple permeability test are shown in **Figure 7**, **Figure 8**. Initial curing was performed on W/C40% and W/C60% for 7days and 28days. As shown in the figure, there was a difference in water permeability due to the addition of the C-S-H based hardening accelerator for both aged 7 and 28days. In addition, regardless of age, the effect of the addition of the curing accelerator was improved for W/C60% than the effect at W/C40%. This is considered to be the same result as the air permeability test.

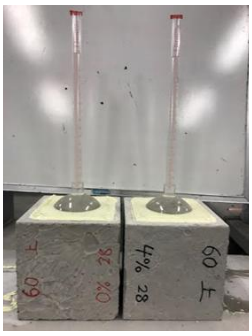

Figure 4: Simple permeability test

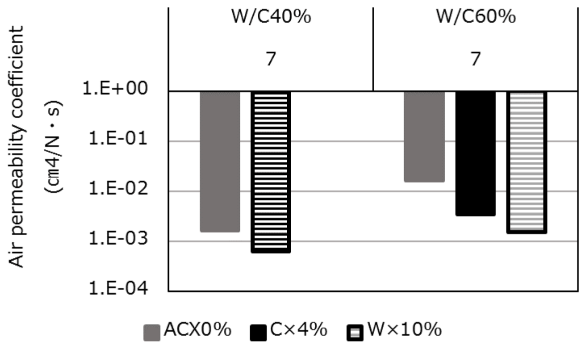

Figure 5: Air permeability test

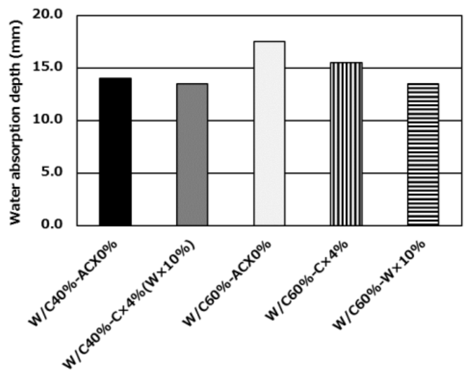

Figure 6: Vacuum water absorption test

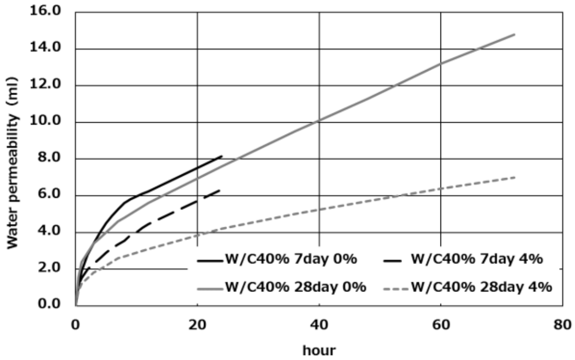

Figure 7: W/C40% simplified permeability test

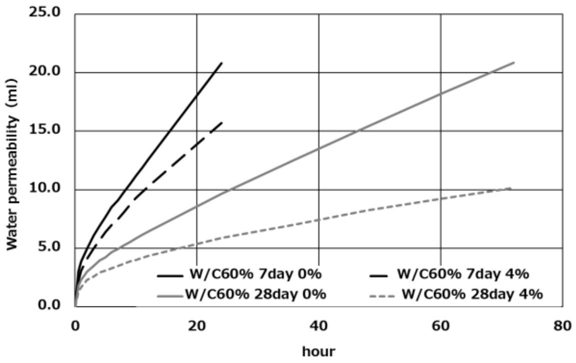

Figure 8: W/C60% simplified permeability test

5. CONCLUSIONS

The results obtained in this study are shown as follow.

When strength development is considered by the C-S-H based hardening accelerator,

(1) Regarding compressive strength development by type of cement in both mortar and concrete, compressive strength development is not recognized with ordinary addition amount. (2) Even in the strength developing property in which the curing temperature is changed, strength development is not recognized in the ordinary addition amount. (3) By setting the concentration of C-S-H in the water to be high, strength development in concrete was remarkably improved. (4) In various durability tests, improvement effect was recognized irrespective of the addition amount.

From the above, it is necessary to decide the amount to be added to the unit water amount, not to determine the amount added to the conventional cement mass as the most effective addition method. It is thought that it is possible to predict the increase in strength even at high water cement ratio and to add it. On the other hand, regarding the durability, it is considered that the C-S-H based hardening accelerator contributes to the densification of the concrete. As a future study, I think that the interfacial transition zones on aggregates inside the specimen were filled with the C-S-H based hardening accelerator. In addition, although it is possible that the gap of the paste portion is dense as discussed from the mechanism, we want to clarify this problem in the future.

6. REFERENCES

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