BASIC PERFORMANCE OF HIGH-VOLUME SLAG CONCRETE USING C-S-H BASED HARDENING ACCELERATOR PART 1

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1. INTRODUCTION

In October 2020, Japan government announced that it aims to reduce CO_2 emissions to zero, to make Japan carbon-neutral by 2050. Construction industry has always strived for effective reduction and control of CO_2 emissions, even more so now than in the past. Concrete, which is an extensively used raw material in the construction industry, uses cement as the binding ingredient. Clinker production during cement manufacturing is a chief contributor to CO_2 emissions. One of the most feasible and economic solutions to reduce CO_2 emissions from cement concrete is by using Supplementary Cementitious Materials (SCMs) like Granulated Blast Furnace Slag (GBFS) to replace Portland Cement. However, using high proportions of GBFS as a cement additive has its drawbacks, critical of which are delaying setting time and exhibiting slow strength development in concrete sensitive to curing conditions.

Hardening accelerators are typically used to increase rate of set and strength gain in concrete. A hardening accelerator containing C-S-H nanoparticles was developed which produced increased rate of hydration in not only tricalcium Silicate but also GBFS [1, 2]. An improved alkali-free C-S-H based hardening accelerator provided similar faster setting times and higher early-age strength in concrete mixed with Type B slag cement [3]. The following study aims to investigate if the alkali-free C-S-H based accelerator could provide faster setting times and higher compressive strength in concrete when Ordinary Portland Cement (OPC) is replaced with higher volumes of GBFS.

2. EXPERIMENTAL PROCEDURE

Table 1 and Table 2 show the raw materials used for the experiment with their physical characteristics and concrete mix design respectively. The water-to-binder ratio (W/B) is set to 40%. The binder used in the mix design is prepared by mixing OPC with GBFS in the ratio of 30:70 (maximum limit for Type C slag cement). Fresh concrete is mixed using a twin-shaft mixer of 55L capacity. The target fresh properties of slag concrete are slump of 18 ± 1.5 cm. and air content of 2 ± 0.5 %. The dosage of the superplasticizer (SP) is adjusted to meet the prescribed slump and air content. The experiment was conducted at room temperature (20°C). The performance in terms of setting time, compressive strength of high slag concrete with and without the C-S-H based hardening accelerator (AC) is evaluated. To do so, Slag concrete with three levels of dosages of AC – 0.0%, 2.0% and 4.0% by weight of binder, were mixed. Slump and air content were measured for each batch while casting specimens to measure setting time and compressive strength. Table 3 shows evauation items and the methods useded. Fig. 1 shows the curing conditions of specimen cast to measure compressive strength.

Table 1 Raw materials used and their physical properties

Raw material	Symbol	Physical properties
Water	W	Tap water
Cement	C	Ordinary Portland Cement (OPC) Density = 3.16 g/cm^3 Specific Surface Area = 3,240 cm^2/g
SCM	GBFS	Granulated Blast Furnace Slag Density = 2.89 g/cm^3 Specific Surface Area = 4,350 cm^2/g
Fine aggregate	S	Land Sand from Oi River water system Surface dry density = 2.59 g/cm^3 Fineness Modulus = 2.57
Coarse aggregate	G	Crushed sandstone from Ome Surface dry density = 2.67 g/cm^3 Maximum dimension = 20 mm.
Chemical admixture	SP	High range water reducer Polycarboxylate ether-based component
	AC	C-S-H based hardening accelerator

Table 2 Mix design of concrete

Slag replacement (%)	W/C (%)	s/a (%)	Unit content (kg/m^3)				
			W	C	GBFS	S	G
70.0	40.0	41.4	165	124	289	725	1049

Table 3 Evaluation items

Item	Test method
Slump	JIS A 1101
Air content	JIS A 1128
Concrete Temperature (C.T)	JIS A 1156
Setting time	JIS A 1147
Compressive strength	JIS A 1106 Specimen dimensions: φ10 × 20 cm. Measured at: (Steam cured) 7h, 17h, 14d (Standard curing) 24h, 3d, 7d, 28d

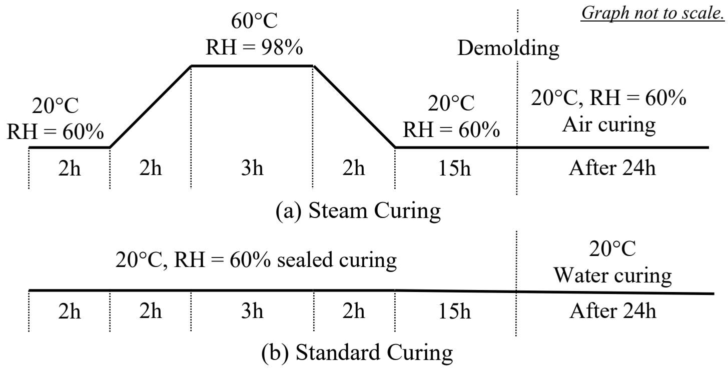

Fig. 1 Curing conditions of concrete specimen.

Keywords: C-S-H based hardening accelerators, SCMs, GBFS, setting, curing, compressive strength.
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3. RESULTS AND DISCUSSION

Table 4 shows the fresh properties of slag concrete with and without hardening accelerator. Batch name of each mix denotes type of Cement, W/B, proportion of slag in binder and the dosage of accelerator AC, in that order. The dosage of SP required to produce identical fresh properties in the slag concrete is slightly lower when AC is added. The hardening accelerator AC contains some dispersant to allow stable dispersion of C-S-H nanoparticles. It might be that the dispersant present in AC, when used, could have influenced the reduction of SP amount necessary to produce slag concrete with similar fresh properties.

Fig. 2 shows the setting times of slag concrete with and without hardening accelerator. It is evident that using the hardening accelerator AC accelerates setting time even in concrete with high volume of slag. Using B × 4.0% AC almost reduced the initial set time by half (from ~4 hrs. to ~2 hrs.). The difference in initial and final setting times remained almost the same in all three batches.

Fig. 3 and Fig. 4 shows the compressive strength development with time under steam curing and standard curing respectively. The hardening accelerator AC provided greater initial compressive strength – 7 hr. strength under steam curing; 24 hr. strength under standard curing even in high slag cement concrete. It has been reported earlier that C-S-H based hardening accelerator increased the rate of hydration reaction of GBFS in GBFS-$Ca(OH)_2$ system [2]. AC could have the potential to enhance initial hydration of GBFS even in higher volume slag concrete. Thus, the difference in the initial compressive strength of slag concrete with and without AC indicates that, despite using high proportions of slag which could significantly hinder initial strength development, the C-S-H based hardening accelerator is very effective as initial strength enhancer.

AC of 2.0%, 4.0% by weight of binder increased 7hr. steam cured strength proportional to the dosage of AC added. When AC of B × 4.0% is used, 7 hr. steam cured strength is equal to that of 17 hr. steam cured strength without AC. At all the dosages of accelerator AC (B × 0.0%, 2.0%, 4.0%), 14-day steam cured strength is approximately the same, implying that using AC doesn't have much impact on long term strength development in high slag cement concrete.

Using B × 4.0% of AC provided higher 24 hr., 3-day and 7-day strength without lowering 28-day compressive strength. A key observation was that the increase in compressive strength from 24 hr. to 3-day and from 3-day to 7-day of no AC, B × 4.0% of AC are equal.

4. CONCLUSIONS

1. Using C-S-H based accelerator provided faster initial set time, early-age strength under standard curing and steam curing at 60°C in high volume slag concrete.
2. In terms of setting time, using C-S-H based accelerator would accelerate the initial set time in high volume slag concrete proportional to the dosage of AC.
3. In terms of compressive strength, using C-S-H based accelerator provided higher early-age strength proportional to the dosage of AC, without affecting long term strength.

Table 4 Properties of Fresh concrete

Batch Name	AC (B × %)	SP (B × %)	Slump (cm)	Air (%)	C. T (°C)
N40-70-0	0.0	0.550	19.0	1.9	20
N40-70-2	2.0	0.525	17.5	1.7	20
N40-70-4	4.0	0.500	19.5	1.5	20

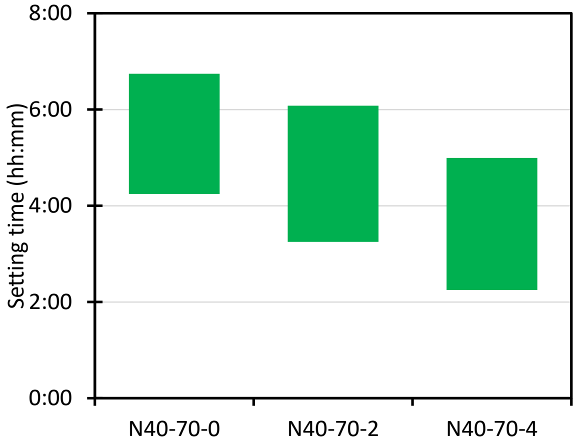

Fig. 2 Setting time

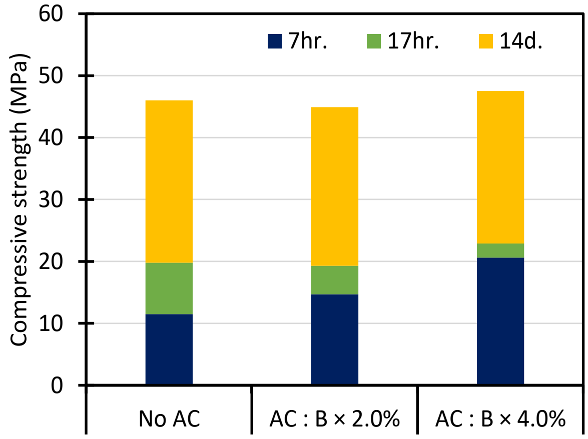

Fig. 3 Compressive strength under steam curing

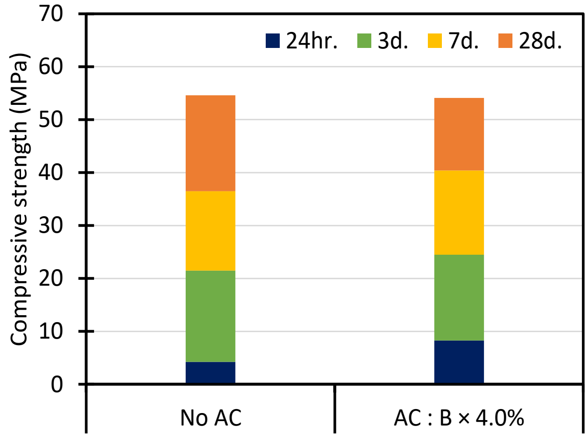

Fig. 4 Compressive strength under standard curing

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