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Mechanical performance of shotcrete made with a high-strength cement-based mineral accelerator

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HIGHLIGHTS

- The mechanical performance of shotcrete that used a HS-CM accelerator was evaluated.
- The shotcrete that used a HS-CM accelerator to enhance the long-term strength performance.
- The test data were statistically analysed at the 95% confidence level.

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ABSTRACT

This research investigated the mechanical performance of shotcrete that used a high-strength cement-based mineral accelerator (HS–CM) to enhance the long-term strength performance. HS–CM was added at 5–8% with respect to the cement weight; the cement-based mineral accelerator (CM) was mixed at 5% for comparison. The setting time, compressive strength, and flexural strength were measured. As the test result, in case of setting time, HS–CM which used more than 6% was slower than CM at initial set; but final set was faster. Compared with the mixture made with the CM, the HS–CM had approximately the same compressive strength at early age but higher compressive strength after 7 days. The trend in flexural strength was similar to that of the compressive strength.

1. Introduction

Shotcrete is an important element in the construction of tunnels or underground spaces. It is used as permanent supports to stabilise cross-sections after excavation. An accelerator is used to achieve the initial strength, reduce rebound, and suppress early ground relaxation. The accelerator is important because it affects not only the early strength of the shotcrete but also the development of long-term strength, durability, and thickness [1–4].

Shotcrete accelerators are classified as alkali-free or silicate-, aluminate-, or cement-based minerals, depending on the main material that is present. The silicate accelerator gives a rapid initial set and a slow final set, while the aluminate accelerator provides a slow initial set and a fast final set. Both types suffer the same deficiency of loss in strength and durability over the long term. Furthermore, their strong alkalinity may endanger workers and lead to environmental contamination. Increasing the accelerator amount adds to the cost and also increases the rebound ratio [1–6]. To alleviate these problems, alkali-free and cement-based mineral accelerators (CMs) that are environmentally friendly and provide good long-term strength are now frequently used in construction sites [7–9].

The alkali-free accelerator has an aluminium compound as its main component and is used mainly in Europe; it is a replacement for silicate and aluminate accelerators. It is less hazardous to humans [5,6].

The CM is a powder accelerator that has calcium aluminate as its main component and is currently used in cement. In this application, large amounts of ettringite are formed. Its early acceleration is so powerful that cement can be laid in wet areas. It is characterised by a lower rebound and lower long-term strength reduction. It is less dangerous to humans at comparable loadings, and its small particle size and powdered form give it good working characteristics and facilitate site quality control [7–9].

A high-strength cement-based mineral accelerator (HS–CM) was developed to provide better long-term strength than a conventional CM. It also has excellent accelerating performance and early strength development. This research studied the accelerating and mechanical performance of shotcrete made with the HS–CM. The results were statistically compared with the data for mixtures made with CM.

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Table 1
Physical properties of cement.

Blain fineness (cm^2/g)	Specific gravity	Stability (%)	Compressive strength (MPa)		
			3 days	7 days	28 days
3,330	3.15	0.08	30	42	58

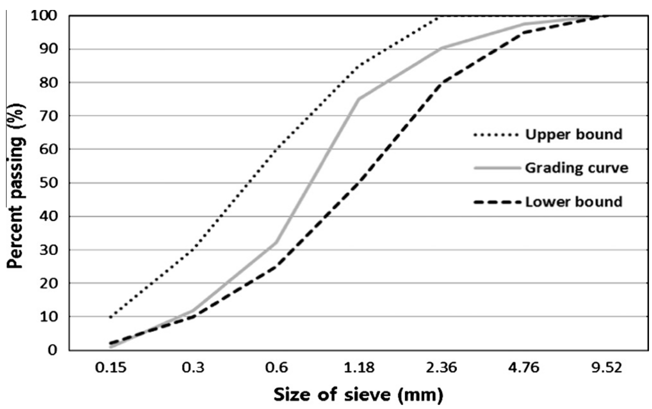

Fig. 1. Grading curve of the fine aggregate.

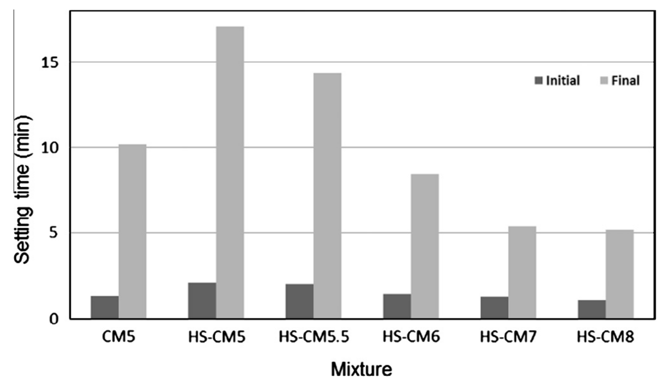

Fig. 2. Test results for the setting time of the mortar with accelerators.

Table 2
Properties of the accelerators.

Accelerator	Component	Type	Specific gravity	pH
HS–CM	$C_{12}A_7$	Powder	2.78	11.65
CM	$C_{12}A_7$	Powder	2.76	11.7

Table 3
Chemical components of the accelerators.

Accelerator	Chemical components (%)			
	CaO	Al_2O_3	Na_2O	SO_3
HS–CM	40.06	32.30	1.69	16.71
CM	40.14	29.57	12.59	0.94

2. Materials and mix proportions

2.1. Cement and aggregate

Type I ordinary Portland cement was used; its physical properties are listed in Table 1. Coarse aggregate, with a specific gravity of 2.69 and a maximum size of 10 mm, was used. The fine aggregate was washed sand having a specific gravity of 2.59 and a fineness modulus of 2.92. The particle size distribution of the fine aggregate is shown in Fig. 1.

2.2. High-strength cement mineral accelerator

A CM is based on the phenomenon that calcium aluminate mineral, which is a type of cement mineral, accelerates setting as it reacts with Portland cement. Its primary component is $C_{12}A_7$, which is amorphous and among the calcium aluminate minerals with the highest accelerating performance [9]. It is now widely used in tunnel construction sites because of its excellent accelerating performance and stable strength development [7–9]. However, over the long term, its strength enhancement is low compared with plain concrete; a high-strength admixture should be used to enhance the long-term strength. The HS–CM was developed to provide early strength and long-term strength without needing a high-strength admixture. The HS–CM is a powder that has calcium aluminate as its main component and is added to a concrete mixture to improve adhesion and accelerate strength development through rapid hardening. The HS–CM follows the same chemical reaction and manufacturing method and also uses $12CaO{\cdot}7Al_2O_3$ as the CM, but additionally contains fine (Blaine 4000–8000 cm^2/g) powdered calcium sulphur aluminate. This material forms the stable ettringite and enhances the long-term strength and durability as it reacts with cement, hardening accelerator, and anhydrous gypsum (added to enhance the speed of later-period hardening and compressive strength development).

To produce the $12CaO{\cdot}7Al_2O_3$ powder, which is the main component of the HS–CM, first, quicklime and alumina by-products are mixed together and the mixture is melted in a furnace. Then, the melt is rapidly cooled by spraying with water and compressed air to form the amorphous $12CaO{\cdot}7Al_2O_3$, which is then ground to a fine powder (Blaine fineness 5000–7000 cm^2/g). To reduce costs, blast furnace slag that has been ground to a powder is used as a finely powdered admixture. The hardening accelerator is made by using one or more of lithium carbonate, sodium carbonate, magnesium sulphate, sodium sulphate, or aluminium sulphate. Table 2 shows the basic properties of the HS–CM used in this research; its chemical components are listed in Table 3.

2.3. Mix proportions

The mechanical performances of shotcretes were measured for mixtures containing HS–CM at 5%, 5.5%, 6%, 7%, and 8% with respect to the cement weight. A mixture containing 5% of the CM was used as a control because that level is accepted as the optimal mixing ratio. A high-strength mixture formulation with a design strength of 45 MPa was used; Table 4 shows the mixing design values. The target slump was 120 ± 20 mm with an air content of 4 ± 1%. Polycarbonate superplasticiser was added to achieve the target slump. Samples are identified as CM or HS–CM, as appropriate, with a suffix corresponding to the mixing ratio.

Table 4
Mix proportions.

Mixture	Accelerator (C^*%)	Gmax (mm)	Slump (mm)	Air (%)	W/B (%)	S/a (%)	Unit weight (kg/m^3)				Admixture (C^*%)
							Water	Cement	Sand	Gravel	
Plain	–	10	120 ± 2	4 ± 1	38	60	190	500	942	652	0.6
CM	5										
HS–CM	5										
	5.5										
	6										
	7										
	8										