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Experimental and statistical analysis of the alkali–silica reaction of accelerating admixtures in shotcrete

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ABSTRACT

This study investigated the alkali–silica reaction of accelerating admixtures for shotcrete. Tests were performed with two types of cement (low- and high-alkali) and three types of accelerating admixture (alkali-free, cement-based mineral and aluminate). An expansion test was performed to determine the alkali–silica reactivity according to ASTM C 1260. The results showed that the expansion increased with the total equivalent alkali content of the specimens. To examine this finding statistically, analyses were conducted at the 95% confidence level. When the low-alkali cement was used, no difference appeared to exist in the expansion after a reasonable period of time regardless of the accelerating admixture. In contrast, when the high-alkali cement was applied, the expansion of the specimens varied with time, although no difference was observed between the expansions of the plain sample and the specimen using the alkali-free accelerating admixture.

1. Introduction

A high alkali content, a reactive aggregate and moisture are essential for creating the alkali–silica reaction (ASR) [1]. If any one of these factors is absent, then the ASR does not occur. ASR can adversely affect the durability of concrete because the alkali–silica gel which is a reaction product can cause serious cracking and overall expansion. Its process can be expressed as follows [2,3].

(1) Silica tetrahedrons (SiO_2) which are one of the main components of reactive aggregate break up due to the attack of hydroxyl ions (OH^-).

$$2SiO_2 + OH^- \rightarrow SiO_{5/2}^- + SiO_{5/2}H$$

(2) If the attack of hydroxyl ions is continued, silicate ions, $H_2SiO_4^{2-}$, H_3SiO_4, and small polymers are formed.

$$SiO_{5/2}^- + OH^- + 1/2H_2O \rightarrow H_2SiO_4^{2-}$$

In this process, swelling N(K)–S–H gel is created by combining $H_2SiO_4^{2-}$ and sodium or potassium ion [4]. N(K)–S–H gel has a low viscosity and can easily move from the aggregates to other parts. The volume of it is increased because it attracts water due to osmosis. At this time, generated local pressure can cause cracking in the concrete.

It is hard to predict the degree of expansion by ASR. Because it depends on the viscosity or stiffness of alkali–silica gel and there are many other factors (such as aggregate type and size, alkali content and temperature) that affect the ASR. In the case of alkali content, if it is increased, reactive silica components react more easily with hydroxyl ions so that the ASR is accelerated. The alkali is supplied mainly from cement or the specific environment, and can be supplied directly from additives, such as the aggregate used or deicing chemicals [5,6]. Swamy and Al-Asali [7] showed that the higher expansion occurred when the specimens were stored in a 4% NaCl than in water. Saccani et al. [8] used four types of sodium additives (NaOH, Na_2SO_4, NaCl, $NaHCO_3$) to examine the effect of alkali content on the expansion due to ASR. As a result, when sodium additives were added, expansion is bigger than those not added. Shehata and Thomas [9] showed that the expansion was influenced by alkali content in cement.

An analysis revealed that the equivalent alkali content ($Na_2O_{eq} = Na_2O + 0.658K_2O$) of Type I Portland cements produced by eight companies in Korea was 0.81–1.14%. These values exceed 0.6%, below which the equivalent alkali content prevents the ASR from taking place [10]. Therefore, the ASR should occur if reactive aggregate and sufficient moisture are supplied. In addition, if an additive containing high alkali is used, the ASR will be greater [8,9].

Shotcrete is used to construct tunnels or underground structures [11]. A low amount of rebounding, good adhesiveness, good shooting, and quick formation of initial strength are basic requirements of shotcrete [11–14]. Therefore using of accelerating admixture is essential to meet this requirement [11]. The

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Table 1
Chemical composition of the cements.

	Alkali content of the cement (%)	
	Low	High
SiO_2	20.51	20.85
Al_2O_3	4.86	4.74
Fe_2O_3	3.38	3.18
CaO	62.22	61.95
MgO	2.57	2.73
SO_3	2.52	2.40
K_2O	1.07	1.50
Na_2O	0.11	0.15
Na_2O_{eq}	0.81	1.14

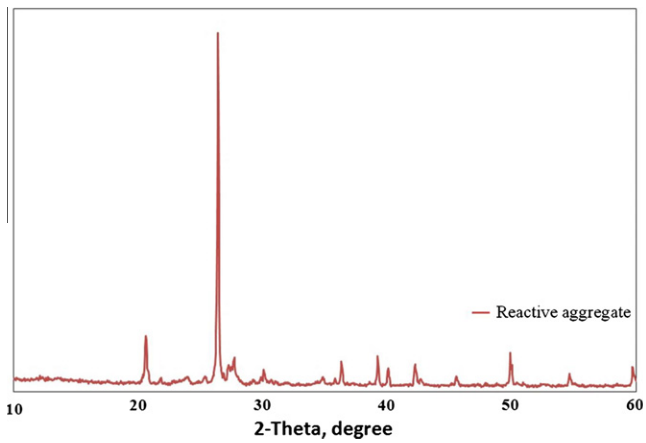

Fig. 1. X-ray diffraction patterns for aggregate.

Table 2
Equivalent alkali content of the accelerating admixtures.

	Alkali content of the accelerating admixtures (%)		
	Alkali-free	Cement-based mineral	Aluminate
K_2O	0.01	0.18	0.02
Na_2O	0.51	13.40	18.80
Na_2O_{eq}	0.52	13.52	18.81

Table 3
Designation of each mixture.

Type of accelerating admixture	Alkali content of the cement	
	Low	High
None	Plain L	Plain H
Alkali-free	L-AF	H-AF
Cement-based mineral	L-CM	H-CM
Aluminate	L-AN	H-AN

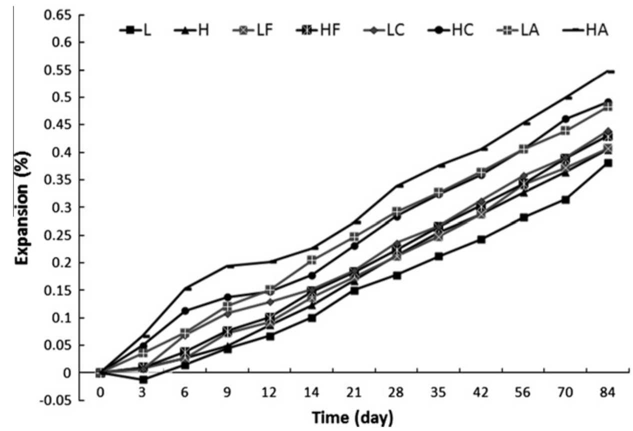

Fig. 2. Expansion test results (L: low-alkali cement, H: high-alkali cement, AF: alkali-free accelerating admixture, CM: cement-based mineral accelerating admixture, AN: aluminate accelerating admixture).

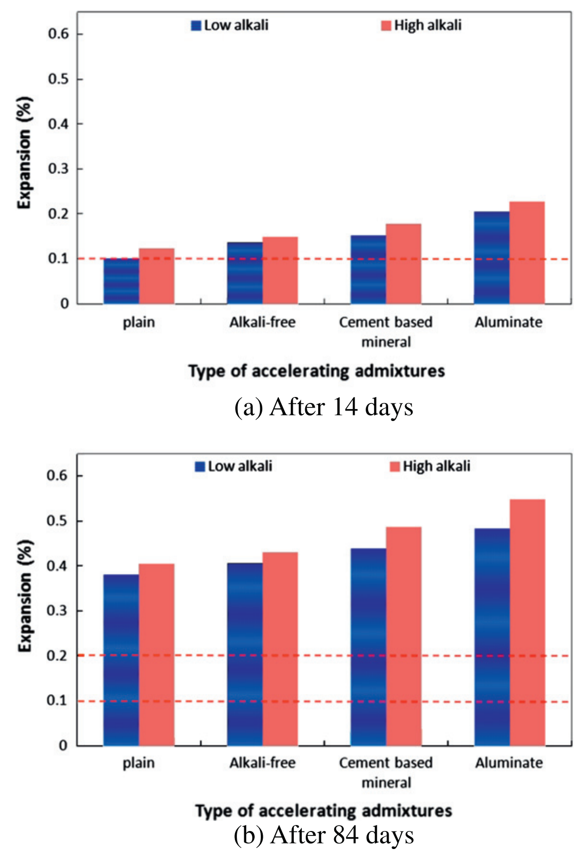

Fig. 3. Comparison of expansion.

accelerating admixture for shotcrete is a supportive material that expedites the initial strength development. It is classified as a hardening accelerator, inorganic alkali, and can include salt and silicate or aluminate, alkali-free and cement-based mineral admixtures [15]. The silicate and aluminate accelerating admixtures were once used the most widely, but they have been banned in many countries because they are potentially harmful to human health. Consequently, a new harmless accelerating admixture that does not result in a long-term reduction in strength is needed. Therefore, alkali-free and cement-based mineral accelerating admixtures were developed [16]. Nevertheless, the silicate and aluminate accelerating admixtures are still used widely for economic reasons, and the ASR may occur because some of these contain high alkali levels. Although the effects of additive materials on the ASR have been investigated [17], no study has examined the effects of the accelerating admixture used for shotcrete.