



Superabsorbent polymers as internal curing agents in alkali activated slag mortars



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HIGHLIGHTS

- Superabsorbent polymers used as internal curing agents in alkali activated slag mortars.
- Various types of alkali activators with superabsorbent polymer tested.
- Superabsorbent polymers reduced the autogenous shrinkage by 60–75%.

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ABSTRACT

The aim of this study was to investigate the potential use of superabsorbent polymers (SAPs) as internal curing agents to mitigate the autogenous shrinkage of alkali activated slag (AAS) mortar. The autogenous shrinkage, compressive strength, hydration, and microstructural characteristics of AAS mortar with a couple of types of alkali activators with SAPs use were investigated. The test results showed that SAPs played an important role in reducing the shrinkage of AAS mortars, which has been a major limitation in their wider application. Higher reductions in porosity were observed for AAS pastes with SAPs compared with those without SAPs.

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1. Introduction

Ordinary Portland cement (OPC) is the most widely used construction material used for producing concrete. However, alkali activated slag (AAS), which contains only ground granulated blast-furnace slag (GGBFS), has been investigated for the last few decades as a promising material for practical applications due to advantageous properties such as high compressive strength, high durability, high acid resistance, and low hydration heat [1,2]. In addition, the use of GGBFS, which is the only binder used to produce AAS mortars and concrete, can play an important role in reduction of carbon dioxide emission by substituting for cement clinkers in concrete production [3,4]. However, drawbacks of AAS include its high autogenous shrinkage, which limits the application of AAS in practical construction applications [5–7]. The shrinkage strains and stresses of AAS mortars are influenced by several

parameters such as alkali activator types and contents, and the curing conditions.

Although many studies concerning the mechanical properties and microstructures of pastes, mortars and concrete of AAS and OPC have been conducted, the shrinkage behavior and strategies for its mitigation have not been extensively investigated [8,9]. Thomas et al. determined that AAS activated by using a sodium silicate solution developed higher chemical shrinkages, almost the double of OPC [10]. Bakharev et al. and Palacios et al. investigated the effect of a shrinkage reducing admixture on the shrinkage reduction of AAS mortars and concrete, while Collins and Sanjayan reported that the pore size distribution significantly influenced the degree of shrinkage strain of the AAS concrete [11–13]. According to research regarding the relationship between pore characteristics and shrinkage of AAS, Shi [4] concluded that AAS mortars and concrete have a lower total porosity and a larger refined pore structure than OPC, which was later confirmed by Collins and Sanjayan [13].

Supplying additional water to mortar or concrete can result in internal curing, which is a method for mitigating high shrinkages.

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This can lead to the reduction of self-desiccation and tensile stress relief inside pores during hydration of the cement paste. Specialized materials have been used to conduct research on the internal curing mechanism; for example, superabsorbent polymers, which contain a reservoir of water in the paste, and lightweight aggregate (LWA) such as pumice or expanded clay in which water was absorbed. Sakulich and Bentz [14] showed that AAS mortars activated by sodium silicate and sodium hydroxide could be used to reduce autogenous shrinkage by using pre-wetted lightweight aggregates. Thirteen international research groups involved with Rilem TC-225 conducted a round-robin test (RRT) to investigate autogenous shrinkage and several mechanical properties of high-performance fine-grained concrete with added SAPs; the test results indicated that SAPs played an important role in shrinkage reduction [15]. In addition, the potential mitigation of autogenous shrinkage was demonstrated by Jensen and Hansen using various types of SAPs for high-strength concrete [16,17].

SAPs have the ability to absorb more than thirty times their own dry weight in water [18]. These water reservoirs, which do not react with cementitious binders during the initial hydration period, play a role in the further hydration of unreacted particles in the mixtures. However, there have been only few studies of shrinkage mitigation and the effects of the microstructure of AAS with internal curing using SAPs, which have great potential for reducing shrinkage. These mechanisms need to be evaluated in AAS mortars or concrete.

The aim of this study is to investigate the effect of SAPs, as an internal curing agent, on the mechanical properties and autogenous shrinkage of AAS mortar. To this end, the effects of the activator type on the autogenous shrinkage, hydration, compressive strength, and microstructural properties of AAS with SAPs were investigated.

2. Materials and methods

2.1. Materials

OPC with a Blaine surface area of 333 m²/kg and density of 3.11 kg/m³ was used. A Bogue calculation of the OPC determined the composition to be 55.5% C₃S, 19.0% C₂S, 7.4% C₃A, and 8.9% of C₄AF by mass. The GGBFS used was produced in South Korea, and its fineness and density were 410 m²/kg and 2.89 kg/m³, respectively. The chemical and physical properties of the binder materials are provided in Table 1.

Three types of activators were used to accelerate the GGBFS reactivity: (1) a powder of sodium silicate with 29.2 wt% SiO₂ and 9.1 wt% Na₂O; (2) sodium hydroxide pellets with a purity of 97%; and (3) sodium carbonate with a purity of 99.5%. Alkali activators used in this study were powder types so that the activation began after water was applied to the mixtures.

SAP powders, which were in white irregular shapes as shown in Fig. 1, were used as shrinkage reduction agent in this study. The SAP powders (LG Chemistry) based on cross-linked poly acrylic acid were produced by gel polymerization method. A single gram of SAP materials could absorb approximately 250 mL of water by the “tea-bag” method [19]. Also, Hong et al. [20] reported the effects of fluid types and concentration on SAP swelling capacity, and SAPs with distilled water developed the largest swelling. The SAPs in the matrix play an important role in curing mixtures by providing extra water inside the swollen SAPs.

Particle size distributions of the raw materials were measured by a laser diffraction method (Beckman Coulter LS 230) using ethanol as a solvent. Fig. 2 shows the particle size distributions and average particle diameter, which is about 220 μm, of the dry SAP powders. Additional water was used to ensure workability of the paste and mortar mixtures with and without SAPs, as described in detail in the following section. ISO standard sands were used as the fine aggregate with a maximum grain

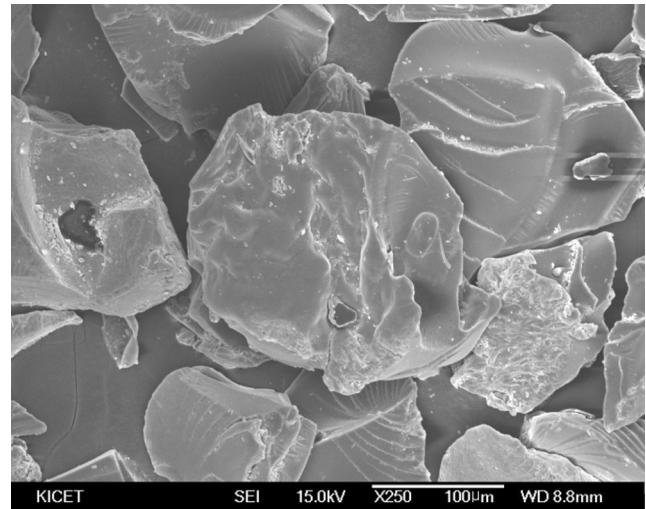


Fig. 1. SEM image of the bulk polymerized SAP powders.

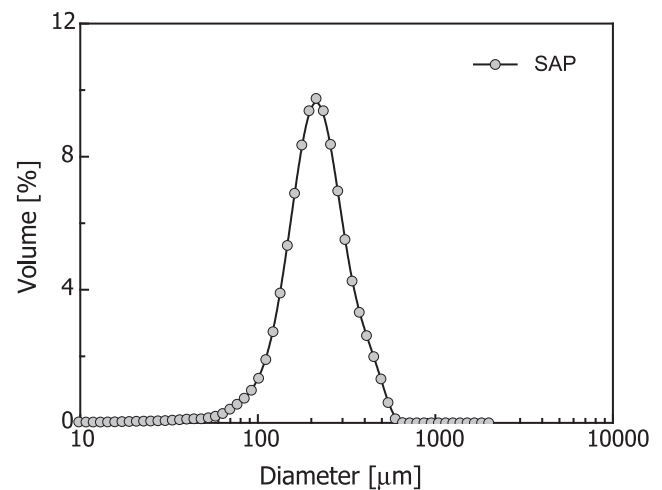


Fig. 2. Particle size distribution of the dry SAP powders.

size of 2 mm and a saturated surface dry density of 2.6 g/cm³. The particle size distribution of the sand complied with the requirements of ISO 679 and the water absorption rate was less than 0.2%.

2.2. Mix proportions

In this study, all mixtures were designed to develop similar compressive strengths without concomitant loss of physical properties, such as workability. Table 2 shows details of the mixtures of the AAS paste and mortar samples. Labels which start with P and M refer to paste and mortar specimens, respectively. Also, the labels with “S” refer to the mixture containing SAPs. Mixtures with PC, SS and SC contain OPC, sodium silicate with sodium hydroxide and sodium carbonate. Na₂O concentrations of alkali activators by binder mass was kept constant at 4 wt% for all mixtures.

The SAPs were added at a concentration of 0.3 wt% of binder to investigate the internal curing effects and shrinkage reduction. Additional water was used in the SAP mixtures to maintain the same slump flow of the mixtures compared to those

Table 1
Chemical and physical properties of the raw materials used in this study.

	Chemical compositions (wt.%)									Density (kg/m ³)	Blaine (m ² /kg)
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	K ₂ O	Na ₂ O	SO ₃	LOI		
OPC	61.9	21.2	4.64	2.91	1.87	1.22	0.29	2.31	2.48	3.11	333
GGBFS	37.2	34.0	16.4	0.50	6.29	0.45	1.33	2.71	0.17	2.89	410

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