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Effect of internal curing by superabsorbent polymers – Internal relative humidity and autogenous shrinkage of alkali-activated slag mortars

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HIGHLIGHTS

- The internal curing effect by SAPs was experimentally evaluated.
- The IRH and autogenous shrinkage were measured.
- The IRH and shrinkage decreased with increasing dosage of SAPs in the specimens.
- The volume fraction of the internal curing zone of the SAPs was modeled.
- The SAPs as internal curing agents are effective for both NPC and AAS mortar.

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ABSTRACT

This study experimentally investigated the effect of internal curing by superabsorbent polymers (SAPs) for mitigating autogenous shrinkage of alkali-activated slag (AAS) mortars. Measured were the compressive strength, the internal relative humidity (IRH), and autogenous shrinkage of AAS mortars incorporating different dosages of SAPs. Test results showed that as the dosage of SAPs increased, the reduction of IRH owing to self-desiccation and autogenous shrinkage both decreased, indicating that the SAPs can be effectively used as internal curing agents. The resulting modeling of the internal curing zone is expected to be useful in determining the appropriate dosage of SAPs in AAS mortars.

1. Introduction

The use of alkali-activated slags (AASs) as an alternative to binders produced from ordinary Portland cement (OPC) has been investigated in an effort to reduce greenhouse gas emissions in the cement industry [1–5]. Although AAS has advantages in terms of early-age strength development, durability, and resistance to chemical attack and heat of hydration [3–5], the significant amount of autogenous shrinkage owing to the formation of mesopores in the microstructure imposes restrictions on applying AAS to actual practice [6–8]. A number of chemical admixtures have been employed to reduce the shrinkage of AAS, including lignosulphonate-based, naphthalene-based, and air-entraining shrinkage-reducing admixtures [9,10].

By pre-securing the moisture absorbed in aggregates with large absorption capacities, additional moisture can be internally provided within cementitious materials [11,12]. Such internal curing is known to be effective in reducing the self-desiccation and autogenous shrinkage of such materials [13]. Lightweight aggregates have been widely used as internal curing agents and have been successfully applied to a variety of materials, including high-strength concrete [9,11], AAS mortar [14], and high-volume fly ash concrete [15]. Superabsorbent polymers (SAPs), which are receiving much attention as internal curing agents [16–20], have been mainly applied to cement-based materials, and they have been shown to be effective in reducing the autogenous shrinkage of high-performance concrete used in bridge decks [19] and high-strength mortar [20]. The existing studies imply that internal curing is effective not only for cement-based materials but also for alkali-activated materials. In particular, SAPs are considered to have strong potential as internal curing agents for reducing the

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self-desiccation and autogenous shrinkage of alkali-activated slag materials.

The purpose of this study was to experimentally evaluate the effect of SAPs as internal curing agents in order to mitigate autogenous shrinkage in AAS mortars. To this end, a series of mortar specimens were fabricated using different types of binders and activators and different dosages of cross-linked sodium polyacrylate as the SAP. OPC and ground granulated blast furnace slag (GGBFS) were used as the binders. Water, Na_2CO_3, and a water-glass/NaOH solution were used as activators. The variations of compressive strength, internal relative humidity (IRH), and autogenous shrinkage of the specimens were then measured over time. By substituting aggregates with SAPs into the existing model [21], the volume fraction of the internal curing zone (ICZ) of the SAPs was estimated and the SAP effects were compared to the test results. The results of the modeling indicate that the compensation ratio of autogenous shrinkage was nonlinearly proportional to the SAP dosage and that the dosage of SAPs required to completely compensate for autogenous shrinkage was different in different specimens.

2. Experiment

2.1. Materials

Type-I OPC having a Blaine fineness of 3499 cm^2/g and a density of 3.13 g/cm^3 was obtained from Ssangyong Cement Industrial Co., Ltd., South Korea. GGBFS, which had a Blaine fineness and density of 4280 cm^2/g and 2.87 g/cm^3, respectively, with an alkalinity of 1.8, was obtained from Posfine Co., Ltd., South Korea. The cross-linked sodium polyacrylate used as the SAP was obtained from LG Chem., South Korea, with particle sizes between 0.15 mm and 0.65 mm. Table 1 shows the chemical compositions of OPC and GGBFS used in the experiment. Fig. 1 shows the particle-size distributions of OPC, GGBFS, and SAP used in the test. The distributions were measured using the laser diffraction method [22] assuming that OPC, GGBFS, and SAP particles were spherical. The average particle size of SAP used in the test was 412 μm. Jensen and Hansen [23] suggested that the efficiency of SAP as internal curing agents increased with decreasing particle size of SAP and the optimum size was about 100 μm. Even though the size of SAP used in the test was greater than the optimum, the existing studies [24,25] indicates that the SAPs, of which the average size was in the range of 300 μm to 1000 μm, were still effective in mitigating the autogenous shrinkage and enhancing the degree of hydration. The alkali activators used in the test included Na_2CO_3 and a water-glass/NaOH solution. The water-glass had a density of 1.396 g/cm^3 and a SiO_2/Na_2O ratio of 3.16; its chemical composition is shown in Table 1. Standard sand with a SiO_2 content of more than 98% was used as the fine aggregates.

Table 1
Chemical compositions of OPC, GGBFS and water-glass.

	OPC (mass%)	GGBFS (mass%)	Water-glass (mass%)
SiO_2	20.5	34.0	29.1
Al_2O_3	5.0	16.4	–
Fe_2O_3	3.0	0.5	–
CaO	61.8	37.2	–
MgO	2.7	6.3	–
K_2O	0.7	0.5	–
Na_2O	0.3	1.3	9.2
SO_3	2.4	2.7	–
H_2O	–	–	61.7
LOI*	2.4	–	–
Sum	98.8	98.9	100

* LOI: loss of ignition.

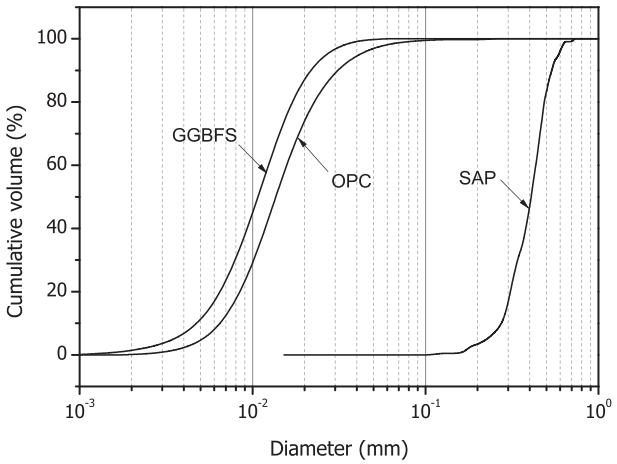

Fig. 1. Particle-size distributions of OPC, GGBFS, and SAP.

2.2. Mixture proportions and test methods

Table 2 shows the mixture proportions of the specimens in the experiment. The NPC series were the reference specimens using type-I OPC and water. The ANC and AWN series used GGBFS as a binder. The ANC series used Na_2CO_3 as the alkali activator and the AWN series used water-glass and a 15 M NaOH solution. The amounts of Na_2CO_3 and NaOH shown in Table 2 were the amounts in the solid state and that of water-glass was the amount in liquid form. The amount of additional water absorbed into the SAP was determined based on the workability, such that the flow of the specimens incorporating SAP was identical to that of specimens without SAP [26]. The flow was measured in accordance with ASTM C1437 and it was 200 mm. In Table 2, the number following the letter "S" in the specimen name indicates the percent of SAP by weight of binder. The ratios of water to binder and binder to fine aggregates were 0.4 and 2.4, respectively, and the amount of fine aggregates was adjusted by considering the volume expansion of SAP upon absorption of water.

Using the teabag method [25], the absorption capacity of SAP was measured depending on the types of pore solutions of the specimens. Even though the use of a cement filtrate solution produces the realistic evaluation of swelling of SAP in the specimens, the existing studies [25,27] indicates that the synthetic pore solutions can be effectively used in determining the swelling of SAP in the cementitious materials. In order to produce aqueous solutions with characteristics similar to those of the pore solution of each specimen, sodium sulfate and calcium nitrate tetrahydrate were used to control the ion concentrations, and KOH was added to adjust the pH [25]. The measured absorption capacities were 54.72 g/g SAP for NPC, 13.8 g/g SAP for ANC, and 29.9 g/g SAP for AWN.

The dry fine aggregates and SAP were mixed at a low speed of 140 ± 5 rev/min for 60 s to ensure homogenous distribution of SAP within the fine aggregates. Subsequently, the mixture of water and the alkali-activator solution were added and mixed at low speed for 30 s, after which the cement or GGBFS was added and mixed first at low speed for 30 s and then at a medium speed of 285 ± 10 rev/min for 30 s. The mixtures were cast into 50 × 50 × 300 mm molds, as shown in Fig. 2(a).

A capacitive-type relative humidity (RH) sensor, SHT75, was used to measure the IRH of the specimens. SHT75 is highly sensitive and reliable and exhibits low hysteresis as compared to electrical resistance-type sensors [28]. The accuracies of temperature and relative humidity of SHT75 were ±0.3 °C and ±1.8%, respectively. Fig. 2(a) shows an RH sensor installed within a protective