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Influence of admixtures on the properties of alkali-activated slag mortars subjected to different curing conditions

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ABSTRACT

This paper presents the influence of shrinkage-reducing (SHR) and superplasticizing and set-retarding admixtures (SSRe) on the properties of slag pastes and mortars activated by liquid sodium silicate with different dosage and modulus ratio. Properties in the fresh and hardened state for these binders were investigated by means of measuring some properties including setting time, flowability, flexural strength, compressive strength, carbonation and shrinkage. In this study, fifteen pastes and mortars were prepared. Liquid sodium silicate was used to activate the slag at two sodium concentrations, 4% and 6% by mass of slag. Liquid sodium silicate and sodium hydroxide were blended to obtain 0.75 and 1 modulus ratio of SiO_2/Na_2O. Results showed that although the higher percentage of sodium in the activator produced a higher strength, workability and setting times rapidly decreased with the higher sodium concentration due to instantaneous reaction and quick hardening of slag activated by liquid sodium silicate. None of the admixtures generally had an impact on the setting times of alkali-activated slag (AAS) pastes. SSRe admixture increased the flow rate of AAS mortars while SHR admixture partially affected the flow values of AAS mortars. SHR admixture exhibited a slight decrease in the carbonation depths of AAS mortars. SSRe and particularly SHR chemical admixtures reduced the shrinkage of AAS mortars. However, the shrinkage values of AAS mortars still were higher than those of ordinary Portland cement (NPC) mortars. Curing conditions had a significant effect on the mechanical behavior in the hardened state of AAS mortars compared to NPC mortars.

1. Introduction

Cement manufacturers blends or intergrinds mineral admixture with the cement to reduce energy consumption, CO_2 emission and increase production [1]. Slag is one of the mineral additives often used as a supplementary cementitious material and partial replacement to Portland cement and, it is obtained during steel production as a by-product. Even though the cement industry utilizes large quantities of slag, there is a still great volume available for use as an alternative binder. The main benefits of using slag in concrete are the better durability and lower heat of hydration as compared to NPC binder. However, the low early strength of these concretes constitutes a restriction in practical applications. This problem can be surpassed by using AAS which is a new type of binder used in concrete technology. These binders, which are a blend of blast furnace slag and activators, have received much attention from the academic field owing to significant advantages such as the lower energy demands and CO_2 emissions in comparison with the manufacturing of Portland cement. Therefore, AAS cement should be considered as an effective binder to produce more qualified concrete than NPC concrete [2].

Results of many researches on this material have been published recently. In comparison with NPC, AAS binders have been found to have higher strength and good performance in chemical attack, frost–thaw cycles and high temperatures [3–6]. Sodium silicate-based activator (either blend of sodium silicate and sodium hydroxide or only sodium silicate) was revealed to have the best strength development performance compared to only sodium hydroxide and sodium carbonate activators [7,8]. However, it has been reported that these binders have a workability problem, and that the shrinkage in most cases exceeds that of NPC concrete [9–11]. Additionally, some researchers [12] indicated that the carbonation rate of AAS concrete was higher than Portland cement concrete for the equivalent compressive strength grade. The disadvantages in question constitute an obstacle for the definitive use of AAS as an alternative to normal Portland cement binders. Thus, these quick setting and high shrinkage problems should be solved to make the use of AAS binders widespread as construction materials.

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Even though the effects of the various chemical admixtures, developed to be used with NPC, have been investigated comprehensively in Portland cement concretes, mortars and pastes so far, their effects on other binders like AAS binders remain to be investigated. In the literature, some researches on AAS binders containing various chemical admixtures have been published [13–15]. However, there are some differences in the results due to some factors such as test conditions, nature and concentration of activator, slag composition, type and dosage of admixture used. Since the utilization of a new material in the cement industry requires a lot of surveys, the additional studies should be performed to contribute to the knowledge at this level. Therefore, the aim of this study is to investigate the influence of SHR and SSRe admixtures on the properties of slag pastes and mortars activated by liquid sodium silicate with the different dosage and modulus.

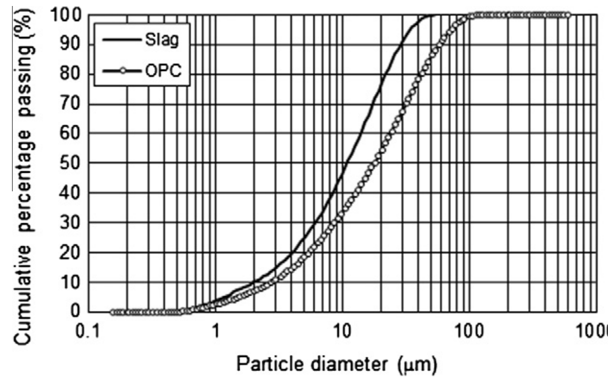

Fig. 1. Particle size distributions of cement and slag.

2. Experimental study

2.1. Materials

The cement used was CEM I 42.5 R. Chemical composition and physical properties of cement and ground granulated blast furnace slag obtained from OYAK Adana cement factory are given in Table 1. The particle size distributions of these materials, which were obtained using a laser scattering technique, are presented in Fig. 1. Sand used in the experimental study was standard Rilem Cembureau type according to TS EN 196-1 [16]. Liquid sodium silicate was used in the alkali activation of slag. Liquid sodium silicate had a SiO_2/Na_2O ratio (modulus, M_s) of 2. SHR based on polypropylenglycol and SSRe based on modified polymer liquid were used as chemical additives. One percent of each admixture by mass of binder was added to the activator solution.

2.2. Experimental program

Water/binder (w/b) ratio of 0.5 was used to prepare paste and mortar specimens throughout the experimental program. In the case of mortars, the sand to cementitious binder ratio was 3:1. For liquid sodium silicate activator, SiO_2/Na_2O ratios of 0.75 and 1 were chosen. These different ratios were obtained by adding sodium hydroxide to liquid sodium silicate. Sodium concentrations in the mixture proportions were also chosen as 4% and 6% by mass of slag. The amount of water in the liquid sodium silicate activator was taken into consideration while adjusting the amount of water to obtain 0.5 w/b ratio in all mixtures. A summary of the experimental program is presented in Table 2.

Table 1
Physical, chemical and mechanical properties of cement and slag.

Chemical composition (%)	Cement	Slag	Physical properties of Portland cement	
SiO_2	18.69	33.78	Specific gravity	3.12
Al_2O_3	5.61	9.55	Initial setting time (min)	190
Fe_2O_3	2.52	0.88	Final setting time (min)	225
CaO	62.68	39.80	Volume expansion (mm)	1.0
MgO	2.63	6.80	Specific surface (Blaine) (cm^2/g)	3200
Na_2O	0.13	0.32	Compressive strength (MPa) of cement	
K_2O	0.77	0.88	2 days	27.2
SO_3	2.73	1.66	7 days	41.0
Cl^-	0.01	0.03	28 days	51.2
LOI	2.88	2.89	Physical properties of slag	
Insoluble residue	0.96	–	Specific gravity	2.78
Free CaO	0.93	–	Specific surface (Blaine) (cm^2/g)	5200
			Pozzolanic activity index (%) of slag	
			7 days	62
			28 days	94

Table 2
Summary of experimental program.

Mix no.	Binder	Activator	Concentration	Admixture
1	OPC	–	–	–
2	AAS	Liquid sodium silicate	4% Na, M_s = 0.75	–
3	AAS	Liquid sodium silicate	6% Na, M_s = 0.75	–
4	AAS	Liquid sodium silicate	4% Na, M_s = 1.00	–
5	AAS	Liquid sodium silicate	6% Na, M_s = 1.00	–
6	OPC	–	–	SSRe
7	AAS	Liquid sodium silicate	4% Na, M_s = 0.75	SSRe
8	AAS	Liquid sodium silicate	6% Na, M_s = 0.75	SSRe
9	AAS	Liquid sodium silicate	4% Na, M_s = 1.00	SSRe
10	AAS	Liquid sodium silicate	6% Na, M_s = 1.00	SSRe
11	OPC	–	–	SHR
12	AAS	Liquid sodium silicate	4% Na, M_s = 0.75	SHR
13	AAS	Liquid sodium silicate	6% Na, M_s = 0.75	SHR
14	AAS	Liquid sodium silicate	4% Na, M_s = 1.00	SHR
15	AAS	Liquid sodium silicate	6% Na, M_s = 1.00	SHR

The initial and final setting times of AAS and NPC pastes were measured using Vicat apparatus in accordance with TS EN 196-3 [17].

According to TS EN 1015-3 [18], flow table tests were conducted to determine mortar flowability, with and without admixtures, after 0, 15, 30, 45 and 60 min (end of mixing). For each mortar mixture, the diameter was measured in four directions following the flow of mortar onto the table of test apparatus.

Prismatic specimens with 40 × 40 × 160 mm dimensions and shrinkage specimens measuring 25 × 25 × 285 mm were prepared from both fresh NPC and AAS mortar mixes for the tests. After 24 h, the specimens were demoulded and cured in three ways until the time of testing; One group of specimens were placed in a humidity cabinet at 23 ± 2 °C with 95% relative humidity (moist curing–MC) while second group of specimens were cured in a humidity cabinet at 23 ± 2 °C with 50% relative humidity (dry curing–DC). In the third method, the specimens were immersed in water and the heater was turned on. The water temperature reached at 65 °C in 2 h and the water temperature was maintained at 65 °C for 5 h. Subsequently, the heater was turned off and, after the cooling periods of the specimens, they were placed in a humidity cabinet at 23 ± 2 °C with 50% relative humidity (heat curing–HC).

The strength tests of the specimens were conducted at 2, 7 and 28 days of age according to TS EN 1015-11 [19]. For flexural strength test, three prismatic specimens from each mixture were used and tested by one-point loading configuration with span of 10 cm. The compressive strength test was performed using six broken pieces of test prisms remained from flexural strength test. The flexural strengths were determined by taking the average of three test results whereas the compressive strengths were determined as the average of six test results.