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Effects of type and dosage of alkaline activator and temperature on the properties of alkali-activated slag mixtures

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Abstract

In this paper the results of a study on the influence of sodium hydroxide, sodium carbonate, and sodium silicate, as activators, and temperatures in the range of 20–31 °C on the setting time and workability of the fresh alkali-activated slag cement (AAS) mixtures are presented. The results obtained show a significant acceleration of the setting of the AAS mixtures versus the setting of ordinary Portland cements. The highest acceleration of the setting was found with sodium silicate, while both sodium hydroxide and sodium carbonate show a moderate effect. The increase of temperature of the mixtures shows the acceleration of setting and decrease of workability. At the sodium silicate a continuous effect was observed as temperature was increased. But with sodium hydroxide and sodium carbonate a sudden acceleration of the setting, and workability decrease were observed, when the temperature reached the values 24–29 °C. © 2006 Elsevier Ltd. All rights reserved.

Keywords: Slag cement; Alkali activation; Sodium hydroxide; Sodium carbonate; Sodium silicate; Fresh mixtures; Setting; Workability

1. Introduction

The goal of sustainable development of the cement and concrete industry is very important, and can be reached if the cementitious and pozzolanic by-products from thermal power plants and metallurgical industries are used. Finely ground granulated blast furnace slag (GrBFS) has been used as an important ingredient of a supplementary binder with ordinary Portland cement (OPC). Since GrBFS itself is nothing more than latent hydraulic binder, it must be activated to react and provide the desirable mechanical properties. Alkali components for the activation of the slag-alkaline cements may be the components like caustic alkalis, nonsilicate salts of weak acid, silicate salts and aluminates [1,2]. Increasingly attention has been paid in the last years on alkali-slag (AAS) cements. However, due to the numerous influencing factors, such as the chemical and mineral composition of the slag, the amount of glassy

phase as well as the type and concentration of activator used, alkali activation of slag is still an insufficiently defined process requiring further research [3]. The importance of such research is expressed by the fact that engineering properties of concretes based on alkali–slag cements are significantly dependent on the process of the activation.

High strength and durability of concretes based on AAS

High strength and durability of concretes based on AAS cements are reported [4,5]. Mechanical properties, as well as other properties of the hardened material, are determined by the nature of the compounds forming during the activation and curing process. It is reported that compressive strength of a hardened material can be high as 100 MPa. But quick setting problems are known. Even the possibility of varied setting times between batches and from mix to mix using one batch of the slag are also reported [6–9].

The use of retarding agents seems to be an effective way. Hundreds of chemical admixtures including water reducers, retarder, surface active agents and dispersants, effective in OPC cement mixtures, have been investigated for the

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retarding of AAS cements in the former USSR [10] and China [11]. But their effects have been found, in some cases, to be different to OPC cement. This may be due to the absence of C₃A and C₃S and the presence of alkaline component in AAS cements. Evidently, the setting mechanism is different from OPC cements [12].

This paper examines the effects of the type and concentration of alkaline activator like sodium hydroxide, sodium carbonate and sodium silicate on the properties of fresh AAS cement mixtures. At the same time the influence of the ambient temperature on the setting and workability, is studied.

2. Experimental

2.1. Materials used

For the experiment the GrBFS with chemical composition and properties given in Table 1 was used.

According to the results of the calorimetric method the slag used represented a pozzolanic material with the decreased initial but with high long-time activity [13,14].

According to the basicity coefficient value of 1.06 and hydration modulus value of 1.46 the slag used represented a material of a weak basicity but able to ensure sound hydration property [15].

As the alkaline activators were used: sodium hydroxide, sodium carbonate and sodium silicate with Ms = 1.13. The values of pH of the activators solutions with the concentration corresponding to 7 wt% portion of the addition of the activators into AAS cement mixture were measured. These represented 12.6 pH at sodium carbonate, 13.4 pH at sodium silicate, and 14.6 pH at sodium hydroxide solution. These values document that all used activators were strong basic substances. The dosage of the alkali activator has no relation with the pH value. It has been reported that when the pH value is higher, the activator shows better slag hydration capacity activation [15]. Therefore, it can be supposed that the pH values of the solutions with lower portion of the activators are the same or near to the given values.

For the study, mortars with a slag:sand ratio of 1:3 were prepared. Alkaline activator water solutions were added with the ratio of the quantity of solution added to slag—sand mixture being 0.5. Different concentrations of activator were used corresponding to 3.0, 5.0 and 7.0 wt% additions of the activators from the slag weight.

Table 2 Composition and properties of ordinary Portland cement CEM I 42.5

Chemical composition	- (%)						
Humidity		0.27					
Loss on ignition 1000	1.91	1.91 2.12 18.26 5.57 2.89 63.51					
Insoluble residue	2.12						
SiO_2	18.26						
Al_2O_3	5.57						
Fe_2O_3	2.89						
CaO							63.51
MgO		1.77	1.77				
SO_3		2.77	2.77				
CaO free		0.88	0.88				
Mineralogical composi	tion (Bog	gue) (%)					
CaSO ₄ C ₄ A	\F	C ₃ A	C ₂ S	C ₃ S			
4.71 8.78	3	9.88	1.61	67.46			
Normal consistence %		32	32				
Initial setting time		2 h 40 min	2 h 40 min				
Final setting time		3 h 40 min	3 h 40 min				
Specific weight		3114	3114				
$(kg \cdot m^{-3})$							
Specific surface		466	466				
$(\mathbf{m}^2 \cdot \mathbf{k} \mathbf{g}^{-1})$							

For comparison the ordinary Portland cement mortar with w/c ratio 0.45 was prepared and used. Its composition and properties are given in Table 2.

The process of the mortar mixtures preparation was as it follows:

The given quantity of the slag was mixed with the given quantity of activator solution during 30 s. After this the silica sand (STN 72 1208), in the quantity corresponding to the slag:sand ratio of 1:3, was added, followed by the mixing of the mixture during 180 s. Then the properties of the fresh mixtures, cured at the chosen temperature, was measured. For this purpose a chamber with temperature controlled electrically was used.

2.2. The properties studied and the methods used

At the fresh mortar mixtures these properties were studied:

• Plasticity using the Haegermann vibrating device and the estimation of the measure of the spreading Sp (cm) of the mortar mix (STN 72 2441 and STN 73 1312),

Table 1 Composition and properties of the slag used

Chemical composition wt%	SiO ₂ 40.19	Al ₂ O ₃ 7.32	Fe ₂ O ₃ 1.16	CaO 42.10	MgO 8.06	SO ₃ 0.80	Loss on ignition 0.30			
Solution heat [13,14]			$2314~\mathrm{J\cdot g^{-1}}$	$2314 \text{ J} \cdot \text{g}^{-1}$						
X-ray analysis			Akermanit	Akermanit Ca ₂ SiO ₄						
DTA			Endotherm.	Endotherm. 740 °C, exotherm. 810 °C						
Basicity coefficient $Kb = 1.06$			Hydration 1	Hydration modulus, $HM = 1.43$						

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