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Analysis of Thermal Properties of Metallurgical Slags

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Abstract

During the process of production of composite heat-resistant materials the ground metallurgical slag can be used as the main component of a binder. The article describes the basic physical, mechanical and thermal properties of the slags under investigation.

Keywords: composites, metallurgical slag

1 Introduction

Composite materials on the basis of ground metallurgical slags and clays can serve as an alternative replacement of expensive heat-resistant materials intended for industrial furnaces lining.

The use of the ground metallurgical slag as a binder for production of composite materials for various purposes has been approved by numerous researches [1, 2].

A slag is the main component of a clay-slag binder that imparts durability in its curing (in the presence of a catalyst) [3, 4]. High physical and technological parameters have been achieved through using the Lipetsk metallurgical plant's slag (further the Lipetsk slag) with the most physically and mechanically suitable clays with slag:clay components ratio =60:40 [4, 5, 6].

Due to the fact that the slag is used as a component of a heat-resistant binder, a lot of attention is drawn to the data on thermal properties of various slags and the possibility of binding free calcium hydroxide by slags in the course of slag-cement binder heating.

2 Experimental study

The researches, carried out by N. A. Fomichev [7], on three types of dump domain slags: dense bright surface slags (chilled), dense opaque surface slags (slowly cooled) and porous slags, showed that the degree of slag crystallization considerably impacts fire properties thereof (table 1). Thus, the opaque surface slag (degree of crystallization - 85-90%) has the best indices. Besides, N.A. Fomichev has established that the fine lustrous slag completely binds calcium hydroxide at the temperature of 400°C while others require higher temperatures.

Table 1: Influence of phase composition of the natural blast-furnace slag on heat-resistant properties thereof [7]

Slag	Fire resistance, °C	Degree of crystallization, %	Deformation temperature under loading		Average coefficients of linear expansion in the interval up to 1000°C	Thermal stability in water cycles
			start	end		
Dense bright surface slag	1150	3-5	760	860	$11{,}94\cdot10^{-6}$	1
Dense opaque surface slag	1080	85-90	-	1260	$11{,}0\cdot10^{-6}$	7
Porous (expanded) slag	1100	65-70	-	1230	$11{,}67\cdot10^{-6}$	3

Thus, the worst thermal-physical properties are shown by the lustrous slag - its minimum fire resistance is one and a half times lower, than that of the heavily glacial slag and its thermal stability is 7 times lower in water cycles. On the other hand, heavily glacial slowly cooled slags are refractory to alkaline activation when curing and may have no curing ability, especially in large filling with clay substances.

In these researches various chemical activations of ground slags were used to identify the most effective one, determining the highest thermal stability. NaOH, liquid glass, Na_2CO_3 soda and Ca $(OH)_2$ lime were used as curing activators. The last three activators appeared to be less effective in terms of ensuring the hydration processes' progress in slags and increasing the durability in curing. However the main parameter of selection of an alkaline activator type was not the durability of a composite, but its behavior at high temperatures and at heat changes.

3 Results and discussion

The experiments findings have shown that NaOH is the best activator for slag curing and thermal stability increasing. Introduction of NaOH to a slag or a clay-slag system in amount of 2% of a binder's mass provides high rates of durability – R(compression)=65 MPa for the pressed clay-slag composites - and imparts a sufficient thermal stability of up to 6-8 cycles of water heat changes.

Sodium silicate, added in amount of 3-6% of a binder's weight in terms of solid, and also in the mix with alkali in the quantitative ratio of NaOH:liquid glass = 1%:1% and 3%:3% of a binder's mass leads to a sudden decrease in thermal stability.

The samples containing clean slag, activated by the liquid glass, with durability of 12-15 MPa collapsed during the first heating-cooling cycle. The clay-slag samples filled with the mix of NaOH and the liquid glass collapsed after 2-3 cycles. It has been established that the higher liquid glass content correlates with the lower thermal stability of a composite material. An increase of the thermal expansion coefficient and decrease of the heat conductivity of a vitreous bundle at introduction of the liquid glass may serve as an explanation thereof.

Additional researches of other types of slags were done to find out their suitability for use (application) in the heat-resistant clay-slag binder. Those were the electrothermophosphoric (ETF) "Togliatti" slag and the cupola "Penztyazhpromarmatura" slag. The slags were subject to grinding to get a specific surface of S=300-330 of sq.m/kg, that for the Issinsk clay was S=496 sq.m/kg. All composites were being filled with water alkaline solution of NaOH (the content of NaOH is 2% in terms of solid) until the humidity of the press powder mix was 12%. The slag and clay-slag samples were pressed at the specific pressure of 20 MPa with subsequent curing under air and moist conditions. The composites and test results are presented in table 2.

The experiments findings have shown that the activated granulated metallurgical slag, ETF slags and the cast cupola slag have sufficient activity and enable to receive a material with high durability (table 2). However, the thermal stability of the slag stone on the basis of the explored slags doesn't exceed 1-2 cycles of water heat changes.

Table 2: Physical-mechanical properties of the granulated slags and clay-slag composites on the basis thereof

№	Structure of a binder, %	Density in a dry state, ρ, г/см^3	Durability in a dried-up state, $R_{сж}$, МПа	Thermal stability, cycle	Loss of durability after calcinating, %
1	Lipetsk slag-100%	1,95	56,0	2	69,64
2	ETF "Togliatti"-100%	1,79	46,3	1	73,93
3	"Penztyazhpromarmatura" slag - 100%	1,86	68,8	1	76,70
4	Lipetsk slag:Issinsk clay = 60:40	2,03	47,6	8	15,00
5	"Penztyazhpromarmatura" slag:Issinsk clay = 60:40	2,09	57,11	3	53,77

The ETF slag is less resistant under conditions of a sudden change of water temperature from 800°C to 20°C. Some of the samples collapsed at the first cycle of tests with a strong snap and almost instant destruction of the sample. The samples on the basis of the "Penztyazhpromarmatura" slag collapsed at the second testing cycle. The ground Lipetsk granulated slag has the maximum 2 cycle thermal stability. The ETF slag and the "Penztyazhpromarmatura" slag are less suitable for production of a heat-resistant clay-slag binder, which can be proved by the fact that their mixes with clay in the ratio 60:40 possess no high thermal resistance while the similar composite on the basis of the Lipetsk slag sustains 8 cycles of water heat changes before complete destruction.

After calcinating the loss of durability of clean slags is at approximately the same level within 69-77% (table 2). Mixing the "Penztyazhpromarmatura" slag with clay leads to greater weakening of the structure (53, 77%) while the loss of durability of samples with the Lipetsk granulated slag after calcinating is 15%.

4 Conclusion

Thus, the researches have shown that among the explored slags the most suitable for use as a component of the heat-resistant clay-slag binder is the Lipetsk blast-furnace granulated slag, in which the CaO content is at the average level and doesn't exceed 41%; it also contains high amount of magnesium oxide (9,37%) and a sufficient amount of aluminum oxide (9,52%).

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