Conference Paper

A Study of the Potential Use of Red Mud to Obtain Compositions Based on Portland Cement

Ekaterina Gerasimova and Elizaveta Gumirova

Department of materials sciences in construction of the Institute of new materials and technologies, Ural Federal University, Yekaterinburg, Russia

Abstract

The paper deals with the problem of utilization of red mud which is a waste product from alumina production using the Bayer method. The principal possible use for the red mud of JSC "Bogoslovsky aluminum plant" (Sverdlovsk region) for the compositions based on Portland cement is shown. It was found that the mud introduction accelerates beginning of the cement paste setting and thickens the paste reducing its mobility. It is concluded that the introduction of red mud up to 30 % is justified in terms of strength indicators. The work is carried out using mathematical planning of experiments.

Keywords: red mud, Portland cement, active mineral additive, composition, properties, bauxite, chemical composition, cement stone strength, mathematical planning of experiments

Corresponding Author:
Ekaterina Gerasimova
e.s.gerasimova@urfu.ru

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1. Introduction

Alumina is a technical aluminum oxide – a white crystalline powder consisting of modifications of α–Al_2O_3 and γ–Al_2O_3. It is obtained by the Bayer method the essence of which is leaching of prepared bauxite with an alkaline aluminate solution with further separation from the aluminum hydroxide solution. Aluminum–containing minerals interact with a solution of caustic alkali (NaOH) whereby aluminum is converted into a solution in the form of sodium aluminate [1].

When receiving alumina by the Bayer method a fine substance (red mud) is formed as a by–product. A characteristic of such muds is a high content of iron and aluminum oxides. They also contain a significant amount of oxides of silicon, titanium, calcium, sodium and other valuable elements, so they can be considered as necessary and useful raw materials. There are a number of works aimed at the development of measures for the recycling of this type of waste as well as the extraction of useful elements from it [2–7].

Unfortunately the bulk of bauxite muds is poured into dumps that creates economic and environmental problems. The maintenance of slurry fields is a very expensive activity; in addition they occupy large areas of fertile lands. When the mud dries, fine particles rise into the air and are carried by the wind for many kilometers around covering the ground with a red bloom. Also it is impossible to avoid drainage of alkaline water from the field and pollution of land and water [8, 9].

To solve issues mentioned above research works for searching of possible ways of red muds recycling in the production of building materials continue [10–12]. The high content of iron oxides does not allow them to be used as main raw material for cement production so they can be introduced into the raw material mixture only as a corrective additive in the production of Portland cement clinker. Technologies of production of ceramic and silicate bricks using bauxite muds have also been developed. Dry mud can be used as a filler of plastics, paints, mastics and other materials [13].

In connection with the relevance of this issue the study of the using possibility of red mud in the cement composition was carried out at the Department of materials science in the construction of Ural Federal University.

2. Experimental Program

Portland cement CEM I 32.5 N (PC) according to Russian Standard no. 31108–2016 and dehydrated red mud (RM) of JSC “Bogoslovsky aluminum plant” (Krasnoturinsk sity) were used as initial materials. Chemical composition of Portland cement is given in Table 1, and red mud – in Table 2.

TABLE 1: Chemical composition of Portland cement (authors' work).

Mass losses of ignition [%]	Mass content [%]					
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
4.00	25.96	3.54	3.61	56.43	1.30	2.93

TABLE 2: Chemical composition of red mud (authors' work).

Mass losses of ignition [%]	Mass content [%]									
	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	P_2O_5	CaO	MgO	Na_2O	MnO	SO_3
7.80	44.00	16.40	8.80	4.60	0.96	9.60	1.10	3.00	0.30	2.90

In accordance with the chemical composition the red mud is characterized by a high content of Fe_2O_3, it has a basicity module equal to 0.42. Despite the fact that the mud is a finely dispersed material its specific surface is 41 % less than that of Portland cement, i.e. it is almost twice larger than the binder (see Table 3). Other properties of cement meet the standard and have the following indicators: normal density – 31 %, the beginning of setting – 2 hours 30 min, the end of setting – 6 hours 40 min, the class of compressive strength corresponds to the manufacturer.

Table 3: The materials fineness (authors' work).

Indices	Portland cement	Red mud
Specific surface [m^2/kg]	320	186
Residue on the sieve no. 008 [%]	2	56

3. Results and Discussion

The works are carried out using mathematical planning of experiments. The conditions of the full factorial experiment 2^2 are shown in Table 4. The water–binding ratio and the amount of introduced mud were chosen as factors.

It was found that the mud introduction accelerates the beginning of setting of the cement paste by 2–3 times and its introduction thickens the paste reducing its mobility (see Table 5). This may be due to the presence of aluminate phases which tend to accelerate the hydration of Portland cement minerals. The decrease in the paste mobility in the mud presence can be explained by the peculiarities of the structure of its particles; most likely, they have a branched surface which increases the water demand of the mixture.

Table 4: Conditions of the experimental design (authors' work).

Factor description	Symbol	Medium value of factor	Interval X_i	Values on the level	
				+1	–1
Water-binding ratio	X_1	0.5	0.2	0.6	0.4
Red mud quantity [%] (Portland cement replacement)	X_2	15.0	30.0	30	0

Further from the obtained mixtures samples were formed which were stored in air-humid conditions and tested for compression when the control hardening time was reached (see Table 6). Regardless of the age of the cement stone the tendency to depend on the compressive strength of the selected factors remains. In the presence of red mud cement stone have more dynamic setting time and gaining strength faster.

Taking into account the calculation of the regression equation coefficients for the compressive strength of the stone at the age of 28 days (see Figure 1) it was found that the increase of W/B ratio adversely affects the strength of the samples (–10.988), and

Table 5: Results of determination of mobility and setting time of cement paste (authors' work).

Composition number	W/B	Content [%]		Setting time		Characteristics of the mixture
		PC	RM	beginning	end	
1	0.4	100	0	4 h 10 min	8 h 00 min	the mixture is connected, but does not spread
2	0.4	70	30	1 h 30 min	5 h 30 min	the mixture is crumbled
3	0.6	100	0	5 h 15 min	9 h 10 min	5.0 cm (ring blurring)
4	0.6	70	30	2 h 10 min	6 h 50 min	the mixture is connected, but does not spread

the introduction of red mud is positive (+7.108). The simultaneous introduction of mud and decrease of W/B ratio have a positive effect on the strength of the stone (+5.733). It was found that the introduction of mud does not reduce the strength of the cement stone with a minimum W/B ratio. The strength of the composition containing 30 % of red mud reaches 55 MPa which is comparable to the strength of the control composition (with out red mud).

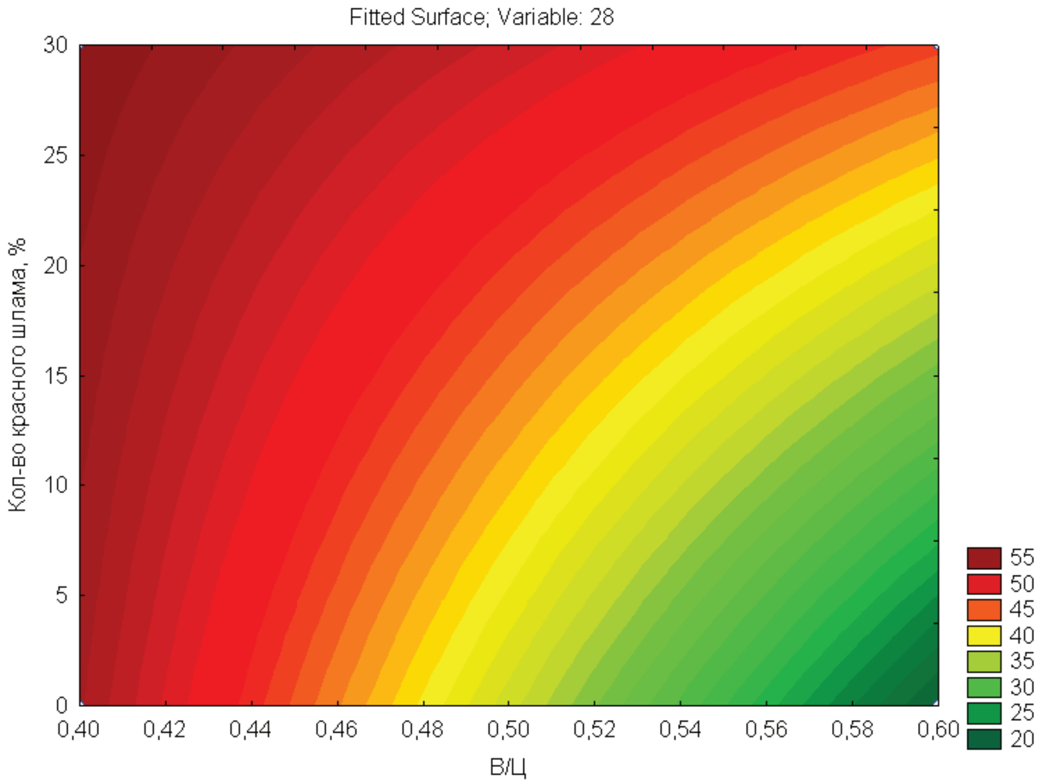
Table 6: Results of determination of cement stone compressive strength (authors' work).

Composition number	Compressive strength [MPa] at the age [days]						
	1	2	3	7	14	21	28
1	6.9	15.1	21.1	37.0	46.4	51.5	53.1
2	23.7	24.3	25.6	40.8	50.0	52.3	55.9
3	1.7	6.7	7.5	10.4	11.7	14.7	19.7
4	5.7	13.4	11.8	22.8	30.2	34.6	45.3

As a result of the first stage of the work it was found that the strength of the cement stone with the introduction of 30 % of the mud slightly increased compared to the strength of the control composition, so at the second stage an experiment to replace more quantity of Portland cement was conducted. Cement compositions containing 40 and 50 % of mud were formed. The water–binding ratio was 0.4, the samples were also stored in air–humid conditions. The results of determining the mobility and time of setting of the cement paste and compressive strength of the stone are shown in Table 7 and Figure 2.

Table 7: Results of determination of cement paste characteristics (authors' work).

Content [%]		Setting time		Characteristics of the mixture
PC	RM	beginning	end	
60	40	1 h 00 min	3 h 20 min	the mixture is crumbled
50	50	0 h 50 min	2 h 50 min	the mixture is crumbled



$$Y = 43{,}538 - 10{,}988X_1 + 7{,}108X_2 + 5{,}733X_1X_2$$

Figure 1: Projection of curvilinear dependence of cement stone strength on the amount of red mud at the age of 28 days (authors' work). $Y = 43{,}538 - 10{,}988X_1 + 7{,}108X_2 + 5{,}733X_1X_2$

4. Conclusions

It was found that a further increase in the proportion of red mud leads to a decrease in the strength of cement stone: with the introduction of 40 % – an average of 13 %, with the introduction of 50 % – 2.5 times. As a result it is concluded that the introduction of mud up to 30 % is justified in terms of strength indicators. In addition it was found that with the introduction of 30 % of the mud water absorption of the stone increases by 19 % and its softening coefficient decreases by 10 % compared to these indicators of the control composition.

Thus it is possible to recommend red mud of JSC "Bogoslovsky aluminum plant" (in an amount of up to 30 %) as an active mineral additive to Portland cement for the preparation of a mixed binder, obtaining mortars and concretes, as well as a component for creating fast-hardening compositions, in particular repair compounds, etc. Of course the presented results can be considered as an initial stage for more large–scale and accurate studies.

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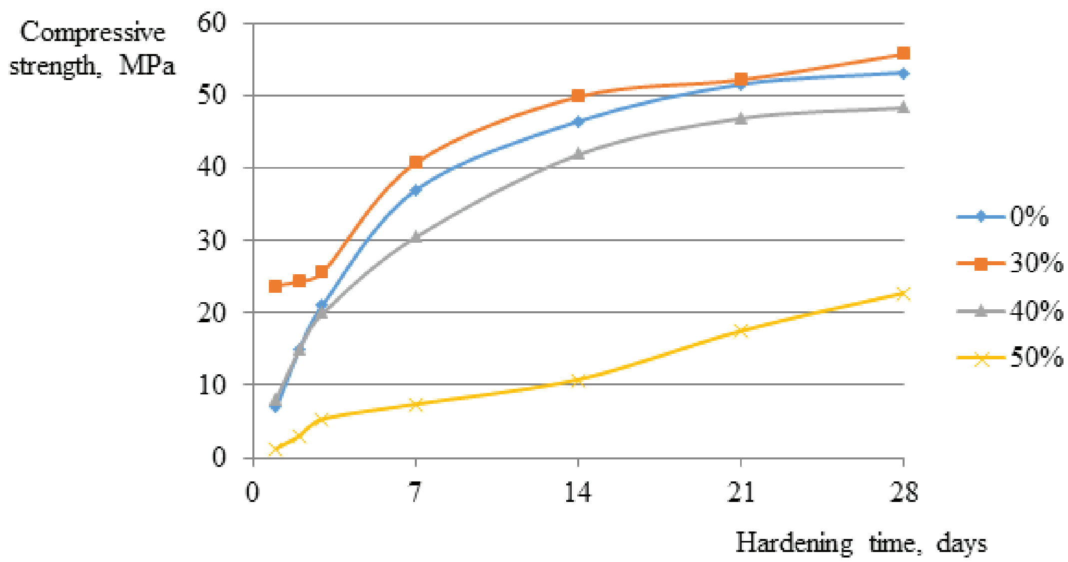

Figure 2: Dependence of cement stone strength on the red mud amount and hardening time (authors' work).

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