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Development and Testing of Low-Energy-Intensive Technology of Receiving Sulphate-Resistant and Road Portlandcement

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Abstract

The article presents the obtaining results of clinkers of sulfate resistant and road cement during the production tests process. The usage of man-made wastes such as lead slag, coal mining waste as well as clay component and additives. X-ray, chemical analyzes of starting materials, clinkers and obtained cements were carried out. The regularities of charge compositions, saturation coefficient, modules, burning regimes on chemical and mineralogical composition and quality of clinkers and cements, improvement of rotary kiln operation, reduction of greenhouse gas emissions and fuel consumption are established. Various methods of analysis were used, calculations of raw mixtures composition were carried out according to the program "Shikhta" (designed to calculate the raw mix and the mineralogical composition of the clinker for the production of Portland cement. The program was developed in the V.G. Shukhov Belgorod State Technical University, Russia) and "Calculation of raw mixtures or CRM" (designed to calculate the raw mix of clinker. The program was developed in the M. Auezov South-Kazakhstan State University, Kazakhstan). The strength of factory and experimental cements was tested after 3, 7 and 28 days and after steaming.

1. Introduction

At present, the intensive industrial and civil construction is underway in Kazakhstan, the volume and range of manufactured building materials and products is growing [1]. Release of cement in 2016 reached 9.03 million tons, which is 5.3% higher than the previous year. The increase in the volume of oil and gas production leads to the need to expand the volume of wells injection, to equip the oil industry, to build infrastructure in the oil regions of the country.

Portland cement is an energy-intensive product. The output of 1 t of cement consumes up to 5 t of raw materials, additives, fuel, water and air, including 220–240 kg of fuel (wet method) and 110–140 kWh of electricity. In the cost of cement clinker, the cost of fuel and electricity costs reaches 50% or more [2–4].

An important problem is also the rational use of various industrial wastes that pollute the environment. Now in dumps and storehouses of processing enterprises of Kazakhstan, more than 30 billion tons of waste have been accumulated, which cause irreparable damage to nature and human health. The volume of waste continuously increases and the time has come for their rational use.

The wastes of industry that we have studied will allow us to partially replace the clay and carbonate component of the raw mix for clinker production.

For the production of low-energy-intensive cements, we used large-tonnage waste from the metallurgical, chemical and coal industries, as well as igneous rocks and clinker burning mineralizers. Together, on the basis of these materials and waste, low-energy-intensive raw mixtures for low-temperature burning of cement clinkers can be obtained. The processes of clinker formation in them complete at temperatures of 1300–1350 °C, which will increase the productivity of rotary kilns by 10–15%, reduce the specific fuel consumption for burning by 10–15%, improve the quality of clinker, increase the output of cement, improve its quality [5–7].

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It has been developed efficient methods for the rational use of lead, copper-smelting, phosphoric and blast-furnace slags in the production of special cements, new compositions of raw mixtures for the production of cements, two-three-flow technological schemes for burning clinker in rotary kilns [7–10].

The efficiency of the low-energy-intensive technologies being developed and the proposed technogenic raw materials lies in the fact that the mineralogical composition of granular blast-furnace, lead, electrothermophosphor slags is close to the composition of Portland cement clinker. Slags in the composition of the raw mix completely replace the correction additive, aluminosilicate component and partially carbonate. As our studies have shown, in some cases it will be necessary to correct the composition of the raw mix with an iron-containing or aluminate component. For this purpose, lead slags and igneous rocks, which contain a significant amount of iron and aluminum oxides, can be successfully used.

2. Raw materials

In order to receive the low energy-intensive raw mixtures, we used limestone of the Sastobe deposit, coal mining waste from the Langer mines, lead slag of the Shymkent plant (Table 1).

We have developed low-energy-intensive compositions of raw mixtures, where instead of the traditional clay component it is proposed to use the coal mining waste of the Lenger coal mines, instead of the deficit pyrite cinder, the granulated lead slag of the Shymkent plant.

Coal mining waste contains more than 55% of silica, 10.6% of aluminum oxide and completely replaces the traditional clay component – loess.

Slags of lead production are formed in large quantities in non-ferrous metallurgy. Thus, when smelting 1 t of non-ferrous metal, the output of slag, depending on the method of production, ranges from 10–20 to 50 t. In factories of non-ferrous metallurgy, tens of millions of tons of slag are stored in dumps and storages. In the heaps of the Shymkent lead factory there are several million tons of slag causing irreparable damage to the environment and human health. Therefore, their utilization as raw materials and additives in the production of Portland cement clinker has an important technological and ecological significance. Lead slag is a fine granular material of black color with a grain size of mostly 0.25–3 mm. The slag consist mainly of fayalite Fe_2SiO_4, melilite, wustite, small amounts of iron sulfides, lead and copper, zinc spinel [8, 11]. Lead slag contains up to 37–40% of iron oxides and can replace the correction additive. In addition, lead slags contain up to 15% CaO and partially replace the carbonate component. These technogenic products have undergone heat treatment in the main process and contain non-carbonate lime. As a result, heat is saved by reducing the mass of the material passing through the energy-intensive decarbonization reaction of $CaCO_3$ during clinker burning.

Coal mining waste consists of clay, carbonate and other minerals and carbon. The chemical composition of minerals is close to the composition of the raw mix for the production of cement clinker. The carbon contained in the waste contributes to the intensification of the grinding process of raw materials, the reduction of the specific energy consumption for grinding, the release of additional heat, and, accordingly, fuel economy and energy savings during clinker burning. Coal mining waste is mainly represented by clay minerals (halloysite, kaolinite, montmorillonites, etc.), quartz, feldspars, calcite, combustible inclusions [8, 10].

3. Research methods

Chemical analysis of raw materials and wastes was carried out according to GOST 5382-91 [12, 13].

Table 1
Chemical composition of raw materials and waste

Raw materials and additives	Chemical composition, mass. %							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss of ignition	other
Limestone	9.48	0.08	0.01	50.71	0.12	0.17	34.7	3.73
Loess	52.07	13.47	4.65	9.35	3.89	0.26	12.07	4.24
Pyritic cinders	13.96	3.87	56.05	1.25	-	3.08	18.3	3.49
Waste coal mining	55.50	10.6	2.01	3.21	0.7	0.79	24.08	3.11
Lead slag	25.94	6.44	37.25	14.71	6.15	0.04	0.1	9.73

X-ray analysis of raw materials, waste and clinkers was carried out on a stationary radiographic device DRON-3, which operates under the following factors: ambient temperature 10–35 °C; relative humidity up to 80% at 25 °C; atmospheric pressure 630–800 mm Hg. [14].

Their raw materials and technogenic raw materials, pre-ground to the remainder of the sieve #008 10–12%, raw mixtures for the production of clinkers were prepared.

Calculations of raw mixtures for the production of Portland cement clinker were carried out according to the formulas of S.D. Okorokov [2, 13]. For calculation of raw mixtures on a personal computer, the program "Shikhta" was used. The program allows to determine the percentage component composition of the raw mix for given values of the saturation coefficient and the silicate module, the theoretical specific consumption of raw materials per ton of clinker, the chemical composition of the raw mix, the modular characteristics, the estimated chemical and mineralogical composition of the cement clinker produced.

The prepared mixtures were moistened, then at a molding pressure of 20 MPa, pellets with a diameter of 2 cm and a height of 1.3–1.5 cm were formed. The pellets were burned in a laboratory electric furnace SNOL 12/16 at a temperature of 1350–1400 °C.

The calcined tablets were ground to determine free calcium oxide and perform X-ray phase and electron microscopic analyzes. The determination of free CaO by the ethyl glycerate method was carried out according to GOST 5382-91 [12]. The method is based on the treatment of clinker or cement with a hot mixture of anhydrous glycerin and absolute alcohol, resulting in the formation of calcium glycerol in the reaction of unbound calcium oxide in the cement and anhydrous glycerin. This glycerate is titrated with an alcoholic solution of benzoic acid or ammonium acetate. Only calcium glycerate passes into the solution. Free magnesium oxide does not react with glycerin.

Physical and mechanical tests of cements were carried out according to GOST 310.2-76-310.4-81 [15–17].

4. Results and discussion

Several series of calculations of three-component raw mixtures based on natural raw materials used in LLP "Sastobe Technologies" and industrial wastes were performed.

The following three-component raw mixtures were selected:

- Limestone + loess + cinder (control mixture);
- Limestone + coal mining waste + cinder;
- Limestone + coal mining waste + lead slag (Table 2);
- Limestone + (coal mining waste + tefritobasalt 1: 1) + lead slag.

The saturation coefficient was 0.90 and 0.92, the silicate module was 2.0 and 2.2. The alumina module was 0.67–0.78, which makes it possible to obtain a low-alumina clinker of special sulfate-resistant Portland cement. The raw materials contain 72.67–73.74% of limestone, 17.48–18.81% of coal waste and 7.77–9.55% of lead slag. Specific consumption of raw materials for the production of 1 t of clinker is 1.514–1.527 t, which is 30–40 kg lower than in the traditional raw meal composed of natural raw materials.

As can be seen from the data in Tables 2 and 3, with an increase in the saturation coefficient from 0.90 to 0.92 and a silicate module from 2.0 to 2.2, the amount of unbound CaO increases, the clinker burning process becomes more difficult. This is explained by the fact that the increase in the silicate module leads to a decrease in the proportion of minerals – C_3A and C_4AF melts, the proportion of minerals – silicates of alite and belite increases.

The amount of liquid phase in the burning clinker with SC = 0.9 decreases from 30.96% to 28.99% or almost 2%, the sintering rate increases from 0.5208 to 0.5650, the burning index increases from 2.8457 to 3.0527 and goes beyond the optimum value of 3.0.

The increase in SC from 0.90 to 0.92 leads to an increase in the clinker content of the most active tricalcium silicate mineral by 4%. The coefficient of sintering and the index of burning are correspondingly higher, the clinker is burned more difficult, which is confirmed by an increase in the content in the clinker of free CaO from 0.68 to 1.12%.

The processes of clinker formation in low-energy-intensive raw mixtures are completed at 1350 °C, i.e. approximately 100 °C lower than in traditional raw materials prepared from natural raw materials. The chemistry of this lies in the mineralizing effect of lead slag on the burning of cement clinker. Zinc oxide contained in lead slag in an amount of 7–12% has a mineralizing effect on the burning process. Lead slag introduces such catalytic elements as Zn, Pb, Cu, F, Mn, Mg, which dissolve in the clinker melt formed during firing, intensively reduce its viscosity, thereby significantly increasing the rate of the limiting stage of clinker formation-the dissolution process in the clinker melt products of solid-phase reactions C_2S, C_3A, C_4AF, CaO [4, 11, 20]. Since clinker formation reactions will proceed at a much higher rate, this will improve the performance of the furnaces without lowering the burning temperature, or without reducing the performance of the calcining units to reduce the burning temperature of the modified clinkers. In both cases, the specific fuel consumption for burning a unit of production will be significantly reduced. In addition, the catalytic additives contained in the slag are optimally affected from the point of view of the influence on the granule formation processes. The structural-sensitive properties of the clinker melt (intensively reduce the viscosity and exert an insignificant effect on the surface tension of the clinker liquid phase), which stabilizes the granulometric composition of the calcined clinker, improves the operation of the rotary kiln, improves the quality of clinker and cement.

Reduced consumption of raw materials per 1 ton of clinker causes a reduction in the specific fuel consumption during burning due to a reduction in the mass of material heated to a sintering temperature at 1350–1400 °C. The total content of the two types of industrial waste in the raw meal is 26.26–27.33% or 401–414 kg/t clinker. The energy-resource-saving technology offered by us will allow us to gradually utilize two types of waste polluting the environment and get rid of two sources that are harmful to the ecology of the southern region.

The indicators of sintering and calcination of the low-energy-intensive raw batch developed are given in Table 3. The proposed raw materials are placed in the optimal indexes for the burning index (2.84–3.05) and sintering (0.52–0.56), thermal calorimetric module (1.52–1.68). The amount of clinker liquid phase is also optimal is 28–30%.

In June 2017, on the rotary kiln #3 of "Sastobe-Technologis" LLP, production tests of energy-saving technology for the production of clinkers of sulfate-resistant and road cements were carried out.

Sulfate-resistant and clinker of normalized composition (for road cement) are obtained from low-energy raw mixes developed at the Chair of «Technologies of cement, ceramics and glass M. Auezov SKSU. Low energy-intensive raw materials for the production of sulfate-resistant and road clinkers include limestone, coal waste from the Langer mines (South Kazakhstan) and lead slag that replace the aluminosilicate component and the correction additive. The chemical composition of raw materials and wastes is given in Table 1.

Production tests were carried out during burning of the traditional factory limestone-loess raw batch with the introduction of cinder and energy-saving raw batch, consisting of 73.74 % limestone, 18.49% of the Langer coal mine waste and 7.77% lead slag for 3 days. The clinker saturation coefficient was 0.92, the silicate module was n = 2.2, the aluminous module was p = 0.78, which ensured the production of sulfate-resistant clinker with a C_3A content of 2–2.5%. The clinker obtained for mineralogical and chemical composition complies with GOST 22264-2013 [18] on sulfate-resistant Portland cement. This clinker of normalized composition is also suitable for the production of road Portland cement (GOST 10178-85), in which the C_3A content should not exceed 8% [19].

The production tests were carried out under different burning conditions, at calcination temperatures of 1350–1400 °C, because lead slag has a mineralizing effect and reduces the clinker formation temperature by 50–100 °C. Coal mining waste

Table 2
Mineralogical composition of sulfate-resistant clinkers from low-energy-intensive raw mixtures and specific consumption of raw materials

Mixtures	Composition of raw mix, wt.%			Specific consumption of raw materials, t/t clinker				SC	Modules		Mineralogical composition of clinker, wt.%					The content of free CaO at 1350 °C,%
	limestone	coal mining waste	lead slag	limestone	coal mining waste	lead slag	Sum		n	p	C_3S	C_2S	C_3A	C_4AF	Sum	
6	72.67	17.78	9.55	1.100	0.269	0.145	1.514	0.90	2.0	0.67	57.34	18.54	0.63	19.52	96.03	0.68
7	73.30	18.81	7.89	1.117	0.287	0.120	1.524	0.90	2.2	0.78	58.30	18.85	2.1	16.95	96.25	1.12
11	73.11	17.48	9.41	1.108	0.265	0.143	1.516	0.92	2.0	0.67	61.51	14.65	0.62	19.29	96.07	1.48
12	73.74	18.49	7.77	1.126	0.282	0.119	1.527	0.92	2.2	0.78	62.52	14.89	2.12	16.74	96.27	1.96

Table 3
Indicators of sintering and burning of low-energy raw materials

Mixtures	The amount of liquid phase, L,%	Index of burning (optimum 2.5–3.0)	n*p	Coefficient sinterability (optimum 0.5–0.6)	Hydraulic-module (optimum 1.7–2.4)	The criterion for the adhesion of the material to the lining (optimum 3.0–3.5)	Thermal calorimetric module (optimum 0.3–1.8)
6	30.96	2.8457	1.3566	0.5208	1.9718	4.9483	1.5229
7	28.99	3.0527	1.7314	0.5650	2.0207	4.9953	1.6887
11	30.60	3.0896	1.3566	0.5647	2.0091	4.9484	1.8303
12	28.65	3.3144	1.7313	0.6127	2.0592	4.9954	2.0434

contains 15–22% of coal and allows to reduce the specific consumption of injector fuel. In general, this will increase the productivity of the furnace and reduce the specific fuel consumption.

After introducing the furnace into the prescribed mode, the regime parameters were taken out every 1 h and clinker samples were sampled every 2 h for physical-mechanical tests. It was necessary to evaluate the effect of dosing of coal mining waste, lead slag on the firing process, the mineralogical composition and structure, clinker activity and the degree of absorption of calcium oxide. The fuel consumption were determined, the productivity of the furnace with energy-saving clinker burning.

Sampling of clinker was carried out from the refrigerator every 2 h. The definition of free CaO was carried out every 2 h per shift and from an average sample, as well as from an average clinker sample, a chemical analysis was carried out. In the workshop "Grinding" in mills of 3×14 m, cements were ground with 5% of gypsum, the specific surface was 270–280 m^2/kg, the rest on a sieve №008 12–13%. In the laboratory, the properties of cements were tested for compliance with the requirements of GOST 22264-2013 and GOST 10178-85 [18–19], samples were molded, and physical and mechanical tests of cements were carried out in accordance with GOST 310.2-76–310.4-81 [15–17].

During the test, the main parameters of the furnace operation were taken into account in the following way: the slurry flow rate was determined from the slurry feed diagrams; output of clinker by the consumption of slurry taking into account dust; fuel consumption by flow meter; Non-returnable dusts with waste gases according to calculation.

Chemical compositions, SC and modules of factory and experimental raw slurries and clinker samples obtained during testing are given in Table 4.

As can be seen from the data, the chemical compositions of SC and the modules of the factory and experimental raw sludge and the clinker obtained in the test as a whole are not significantly different. When grinding experimental raw slurry into the mill, 18.5% of the coal mining waste and 7.8% of the lead slag were injected into the mill.

Technological indices characterizing the properties of factory and experimental raw sludge, the operation of the rotary kiln, obtained during the production tests, are given in Table 5.

Table 4
Chemical compositions, SC and modules of raw slurries and clinkers

Raw sludge and clinker	Chemical composition, mas. %							SC	Modules	
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss of ignition		n	p
Raw sludge										
Factory	13.57	2.53	2.89	45.33	0.64	0.24	34.27	1.057	2.5	0.88
Experimental	13.50	2.51	2.90	45.42	0.67	0.28	33.49	33.49	2.49	0.87
Cement clinker										
Factory	22.49	4.13	4.38	67.36	0.92	0.24	-		2.64	0.94
Experimental	22.42	4.39	4.8	67.39	0.9	0.27	-		2.63	0.91

Table 5
Technological parameters of raw sludge, fuel and furnace operation

Indicators	Dimension	Value of indicators	
		Factory raw batch	Experimental
Duration of the test	h	72	72
Slurry consumption per test	t	3526	4078
Slurry moisture content	%	38	36
Slurry flow ability at the TN-2 fluid flow meter	mm	65	64-65
Bulk density (density)	kg/l	1.623	1.62
Titer	%	79.88	80
Fineness of grinding-residue on a sieve: №02 №008	 % %	 3.5 11.5	 3.6 11.7
Supply (injection) of dust from electrostatic precipitators	t/h	3.6	3.56
Coefficient of saturation		1.057	1.056
Content of CO_2 in raw materials	%	34.27	33.12
Clinker production for testing	t	2150	2471
Weight of 1 l of clinker	g	1580	1570
Temperature at the output of the refrigerator	°C	80	62
The content of free CaO	%	0.62	0.52
Petrography of clinker Alit, % Belit, % C_3A, % C_4AF, %		 69.34 12.16 3.32 13.32	 69.2 12.0 3.20 13.60
Temperature of exit gas	°C	220	223
Mark of used fuels	Coal mine Maikuduk		
Consumption for testing	t	817	760.6
Moisture of raw coal	%	11	11.2
Moisture of injector coal	%	1.3	1.4
Fineness of grinding of injector coal – residue on a sieve: # 020 # 008	 % %	 2.4 12.1	 2.5 12.0
Maintenance of flying V_{dry}	%	33	33.2
Ash content dry	%	20	20.1
Calorific Value	KDj/kg	4920-5105	4940-5200
Temperature	°C	68	70
Indicators of furnace operation			
Productivity	t/h	30.0	34.53
Productivity increase	t/h-%	-	4.53-15.1
Specific consumption of natural fuel	kg/t	380	307.8
Specific consumption of reference fuel	kg conditional fuel/t*Kl	271	219.5
Reducing specific fuel consumption	%	-	19

The consumption of the experimental slurry for the test was 4068 t, the moisture content of the slurry decreased from 38% to 36% or 2% due to the introduction of waste products having a lower moisture demand. Coal mining waste contains up to 20% of coal and has an intensifying effect on the process of fine grinding of raw materials in tubular ball mills, reducing the specific consumption of electricity for the process of grinding raw materials.

The experimental low-energy clinker for the test was 2471 t. In the process of roasting of a low-energy-intensive raw batch, an improvement in the operation of the rotary kiln has been established, the quality of the clinker is good, the weight of the clinker liter has decreased slightly, the clinker is more porous due to coal burn-out from the coal waste, the free CaO content is 0.5–1.5%, the coating in the sintering zone is stable, The burning temperature has decreased by approximately 100-110 °C, the average hourly capacity of the furnace has increased from 30 t/h to 34.5 t/h or 15.1%, the consumption of natural fuel has decreased from 380 kg/t to 307.8 kg/t or by 19%, the conditional fuel consumption decreased from 271 to 219.5 kg conditional of fuel per ton of clinker.

The chemistry of improving the processes of clinker formation in the low-energy-intensive raw mixtures developed by us consists in the mineralizing effect of small components of lead slag on high-temperature mineral formation reactions. Zinc oxide and other catalytic compounds contained in lead slag are effective mineralizers for calcining cement clinker. They contribute to the improvement of the properties of clinker melt, the rapid dissolution of silicates, aluminates, aluminoferrites and calcium oxide that have formed earlier in the melt, with the crystallization of tricalcium silicate. There is a clear crystallization of minerals, their distribution is uniform. The clinker is represented by small-, medium- and less often coarse-grained alite, and the belite crystallizes in the form of rounded crystals.

Thus, the efficiency of burning of low-energy raw materials developed by us is proved in the industrial conditions at the industrial furnace of a cement plant.

The clinkers obtained during the tests were ground in cement mills with dimensions of Ø3×14 m and sulfate-resistant and road Portland cement were obtained. The grinding was made to the same fineness by the remainder on the sieve #008 12.1–12.3%, the specific surface area of the cement was about 270 m^2/kg. Cements withstood the test for the uniformity of volume changes, the normal density of the cement paste and the setting time are within the requirements (Table 6). The beginning of setting of experimental sulfate-resistant cement comes in 2 h 10 min, the end after 3 h 20 min.

The physical and mechanical properties of the factory and experimental cements according to GOST 310.4-81 were studied on samples – 4×4×16 cm in size hardened in water and in a steaming chamber.

The results of tests for the strength of samples of 4×4×16 cm of factory and experimental test cement are shown in Table 7.

As can be seen from the data in Table 7, the ultimate strength of the obtained sulfate-resistant and road cements increases with increasing hardening times. After 28 days, the strength of the cement during bending is 6.7 MPa, while compression is 45.4 MPa. These figures correspond to the cement brand for strength M400. The strength of steamed specimens 4×4×16 cm was 4.6 MPa at bending, and at compression – 30.3 MPa.

Table 6

Normal density and setting time for cements

Cement	Residue on screen #008,%	Specific surface, m^2/kg	Uniformity of volume change	Normal density,%	Setting time, h-min	
					Start	end
Factory	12.3	270.6	withstood	26.0	2-10	2-00
Experimental	12.1	270.1	withstood	26.0	3-20	3.10

Table 7

Physical and mechanical properties of factory and experimental Portland cement

Cement	Residue on a sieve #008,%	Strength of samples 4×4×16 cm, MPa, after							
		natural hardening						steaming	
		bending			compression			bending	compression
		3 day	7 day	28 day	3 day	7 day	28 day		
Factory	12.3	3.25	4.86	6.72	22.1	36.2	44.7	4.53	29.4
Experimental	12.1	3.28	4.58	6.70	23.0	35.9	45.4	4.60	30.3

4. Conclusions

1. Production tests at LLP "Sastobe Technologies" showed the possibility of energy-efficient burning of clinkers of sulfate-resistant and road cement based on raw mixes including limestone, 18.5% of coal mining waste in Lenger mines and 7.77% of lead slugs.

2. In the process of roasting of a low-energy-intensive raw mixture, an improvement in the operation of the rotary kiln was established, the quality of the clinker was good, the free CaO content was 0.5–1.5%, the coating in the sintering zone was stable, the calcination temperature decreased by approximately 100–110 °C, furnace increased from 30 t/h to 34.5 t/h or 15.1%, natural fuel consumption decreased from 380 kg/t to 307.8 kg/t or 19%, the consumption of conventional fuel decreased from 271 to 219.5 kg conditional of fuel per ton of clinker.

3. The chemistry of the improvement of clinker formation in the low-energy-intensive raw mixtures developed by us consists in the mineralizing effect of small components of lead slag on high-temperature mineral formation reactions. Reducing the specific fuel consumption is due to reducing the moisture content of the slurry from 38% to 36%, reducing the clinker burning temperature from 1450 °C to 1350 °C, reducing the proportion of carbonate lime when introducing slags in the proposed feed mixtures.

4. The strength of sulphate-resistant and road cements after 28 days with bending is 6.7 MPa, at compression – 45.4 MPa, which corresponds to cement grade by strength M400. The strength of standard samples after heat moist processing at compression was more than 30 MPa.

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