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Modern trends in the development of cement production

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Abstract. The modern trends in the development of cement process technologies include: high individual production line capacity reaching 12.000 tons of clinker per day, informatization, digitalization of production management, intellectualization of cement equipment operations, the use of artificial intelligence, widespread use of industrial waste, alternative fuels, energy-saving production processes, and reduction of carbon dioxide emissions.

The paper examines the possibilities of using industrial waste as raw materials for producing low-temperature clinkers and mineral additives in composite cements in order to reduce CO_2 emissions.

Low-energy compositions of raw mixtures for clinker production have been developed, which include coal mining waste, lead slag, tephrite-basalt, and clinker from the agglomeration of zinc ores. In these raw mixtures, waste replaces up to 20-25% of natural raw materials, allows clinker formation to complete at 1300–1350°C, increases kiln productivity, and reduces carbon dioxide emissions into the atmosphere by 15-20%. Burnt clay shales from the Betpakdala and Kuyuk deposits were studied as active mineral additives in composite cements to reduce the clinker component, reduce carbon dioxide emissions into the atmosphere, and improve the environmental situation. The processes of shale burning were studied, and the activity of mineral additives was determined depending on the heat treatment temperature. Composite cements with active mineral additives of up to 15% by weight were obtained.

Keywords: zinc ore Waelz clinker, clinker burning, waste, low-energy technologies, composite cement, clay shale

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Introduction

Cement is the most important binder, and cement and concrete based on it remain the main resource materials consumed in all areas of construction. The cement industry plays a key role in the construction industry of Kazakhstan and the world. The cement industry bears an important responsibility for capital construction and plays an invaluable role in the process of industrialization, urbanization and modernization of all countries. At the same time, a new wave of scientific and technological revolution has had a profound impact on cement production methods, which are gradually moving towards high class, intellectualization and greening, standing at the forefront of an era of great changes unseen in a century. They contribute to a more qualitative, efficient and sustainable development of the cement industry, and solve the issues facing the development of the global cement industry [1, 2].

The main problems of cement production are high fuel and energy intensity, as well as environmental pollution with carbon dioxide emissions. The clinker firing temperature in a rotary kiln reaches 1450 °C, the fuel consumption in the kiln and decarbonizer to produce 1 ton of clinker is 110–120 kg of conventional fuel, while up to 850–900 kg of CO_2 is emitted into the atmosphere for each ton of clinker produced.

The state of issues of industrial waste disposal in cement production

Since the 1970s, cement companies have been studying and working to replace natural resources with production waste. With the development of science and technology and the increasing awareness of people about environmental protection, the issue of sustainable development is receiving more and more attention. The Eco-Cement cement plant was established in Japan in the mid-1990s. In the ratio of cement raw materials, the proportion of ash from the incineration of municipal waste and sewage sludge approached 50%. Half of the cement plants in Japan recycle various waste. In 2002, the average waste utilization of cement plants in Japan was more than 355 kg per ton of cement. European cement companies recycle more than 1 million tons of hazardous waste per year. In Europe, combustible waste is widely used as an alternative fuel for clinker burning in rotary kilns and calciners [2, 18].

Most cement plants in the United States use waste fuel as raw materials and fuel, with the overall fuel substitution rate in these companies ranging from 10 to 20%.

For the production of Portland cement clinker, it is proposed to use large-tonnage technogenic waste from the metallurgical and chemical industries, as well as igneous rocks and various mineralizers of the clinker firing process. Many wastes are close in composition and properties to natural raw materials, but are much cheaper than the extraction of natural ones [3].

Currently, the disposal of technogenic waste is one of the significant problems of the modern world. In developed countries, a significant amount of technogenic materials are utilized in the production of Portland cement, since cement production is a large-tonnage process. Scientists have developed effective ways of using technogenic waste as raw materials, mineral and fuel-substituting additives. Some technogenic products have already undergone heat treatment in the process of producing the main products, and some of them contain a number of clinker minerals [4].

The use of the calcium cycle has been chosen as the most suitable option for capturing CO_2 for this application. The reuse of the CaO waste generated by CO_2 capture in a cement plant and the recovery of the energy released from the cooling and clinker capture system to generate additional energy are the main advantages of this proposal. In this work, flow charts and heat and mass balances are calculated. The results show a low CO_2 reduction cost of 12.4 €/t, which is lower than any other combination of a power plant with a capture system or a cement plant with a capture system, making this proposal economically very attractive. In addition, due to the increased energy efficiency, the reduced use of raw materials and decarbonized materials, and the CO2 capture system, a significant amount of CO_2 emissions can be avoided by 94%. (Luis et al., 2021) [5].

The solution to energy saving and ecology issues in cement production is waste disposal, replacement of a part of clinker with high cost price with natural or artificial, i.e. natural or man-made additives, production of low-clinker cements [6-8]. Additives are not available in all regions where cement plants are located. The most accessible are pozzolans, blast furnace, phosphorus slags, ashes, etc. The task of researchers is to find and increase the range of

One of the ways to reduce the amount of harmful emissions into the atmosphere, carbon dioxide released during the production of Portland cement clinker is the use of active mineral additives containing silicon dioxide, which reduce the proportion of clinker in the composition of cement. That is, it is necessary to develop effective compositions of composite cements in which part of the expensive clinker is replaced by active mineral additives. Reducing the proportion of clinker accordingly reduces the volume of CO_2 emissions into the atmosphere. This is a pressing global problem that is of concern in Europe, the USA, China and all other countries of the planet [9-12].

In recent years, the cement industry has paid much attention to mineral additives. This is not a new direction, because for several decades, standards have allowed the use of limestone, slag, pozzolana, ash and dust as additives. But the renewed interest in optimizing the use of these materials can be considered relevant today. The use of additional raw materials here - mineral additives allows not only to reduce the cost of cement (in most cases, these materials are much cheaper than clinker), but also to reduce the specific amount of CO_2 emissions [13, 14].

Sivkov S.P. et al. studied the thermodynamic activity of compounds in Portland cements that harden during carbonation and hydration, and also calculated the level of partial pressure of CO_2 and established the activity of carbonation of CO_3^{2-} in mineral compounds. The authors found that the compounds are capable of carbonization under the influence of dry or wet carbon dioxide to form calcium carbonates [15].

Smolskaya E.A. et al. in their work considered the effect of thermally activated clays on the properties of Portland cement. The authors found that thermally activated clays can replace up to 25% of Portland cement clinker without loss of strength and quality of cement, which made it possible to reduce carbon dioxide emissions during cement production [16]. Ram K. et al. studied the effect of kaolinite concentration from two separate clays (collected in the East and South-Eastern Europe) on the durability of concrete. Clay with a low kaolinite content contained 18% kaolinite, while clay with an average kaolinite content contained about 41% kaolinite. The authors proved that kaolinite content has a moderate effect on compressive strength, but has a significant effect on other durability indicators [17]. By a government decree in the Russian Federation, starting in 2025, cement plants are required to use at least 6% recycled raw materials in cement production [19].

In addition, there has been a boom in research and development around the world to green cement technology and improve the characteristics of environmentally friendly cement concrete.

Back in 2021, at the G20 summit, the countries expressed their intention to stop greenhouse gas emissions by the middle of the 21st century [20]. Countries intend to formulate long-term strategies to achieve zero emissions by 2030. G20 leaders called for keeping climate change at 1.5 degrees, but this will require "meaningful and effective action and commitment from all countries."

Heidelberg Cement is launching a pilot project to capture CO_2 [21]. The ACCSESS project is being implemented in a consortium with the Norwegian Sintef Energi AS, which leads the community. The consortium includes 18 partners. The aim of the project is to significantly reduce the costs in the CCUS (Carbon Capture, Use And Storage) value chain and to develop transport systems to optimize the delivery of CO_2 emissions from mainland Europe to CO_2 storage areas in Scandinavia and the North Sea. As part of the ACCSESS project, Heidelberg Cement will be the first company to use CCUS in Eastern Europe by launching a new CO_2 capture technology at its cement plant in Gurajdzha, Poland. The emission capture plant allows for greater use of waste heat and simplifies the monitoring of secondary emissions. In Uzbekistan, automatic emission tracking systems have been installed at a number of cement plants in order to study the impact of industrial enterprises on the environment. A "stationary observation point" has been created at Akhangarancement JSC, located in the Tashkent region. This serves as an important factor in reducing the impact of industrial enterprises on the environment of adjacent territories [22].

Heidelberg Materials has launched the world's first zero-carbon cement in Europe under the new brand evoZero [23]. evoZero achieves a zero-carbon footprint by using carbon dioxide capture and storage technology at the Heidelberg Materials plant in Brevik. The CO_2 capture and storage technology does not change the existing cement production process; the chemical composition and properties of the cement remain the same. The zero-carbon technology therefore covers the entire range of cements from CEM-I to CEM-III. The installation at the Brevik cement plant is the world's first industrial-scale CO_2 capture facility. Completion of the facility is scheduled for the end of 2024. Once operational, 400,000 tonnes of CO_2 per year will be captured and stored, which corresponds to 50% of the plant's emissions and is equivalent to taking around 180,000 cars off the road. The British Gauldon plant [24] will use 20 thousand tons of ceramic waste and industrial scrap as an alternative raw material in cement production. Recycled ceramics will partially replace natural slate.

Summarizing the above material, the following can be noted:

1. Portland cement with active mineral additives is an easily produced and popular material today;

2. Research on the development of composite cements is aimed not only at reducing the cost of Portland cement, improving environmental conditions, but also at ensuring high quality of the resulting products and using local reserves of available raw materials;

3. Rational waste disposal will significantly reduce the carbon footprint of cement production.

The methodology

The aim of this research is to study the possibility of using industrial waste as raw materials for obtaining low-temperature clinkers and mineral additives in composite cements.

In this work, waste from crushing limestone from the Sastyubinskoye deposit, clinker from the Waelz zinc ore of the Achisai metallurgical plant, electrothermophosphorus slags from the

Novo-Dzhambul phosphorus plant in Taraz, and waste from coal mining in the Lenger mines (Turkestan region) were studied to obtain clinkers as alternative raw materials and corrective additives. All of the above technogenic raw materials are located in close proximity to three large cement plants in Southern Kazakhstan - Standard Cement LLP, Shymkentcement LLP and SastobeTechnologies LLP. Accordingly, logistics and transportation costs for delivering industrial waste to these enterprises will be affordable.

To study the composition of raw materials, industrial waste, and the obtained cement clinker, chemical analysis methods were used according to GOST 5382-2019 Cements and materials for cement production. Chemical analysis methods [25]; X-ray phase analysis of raw materials and clinkers was carried out on a DRON-3 derivatograph [26], an ENDEAVORD8 diffractometer, and an X-ray (S8 Tiger) device [26-28]; electron microscopic studies were performed on a JEOL JSM-6490 LV microscope [26, 28]. The quality of clinker firing was assessed by the content of undigested (free) CaO, which was determined by the ethyl glycerate method [29].

The chemical and mineralogical composition of natural and technogenic raw materials was studied, and the possibility of their rational use in the production of clinker and cement was established (Table 1).

Table 1. Chemical composition of natural and man-made raw materials

Natural and man-made raw materials, deposits	Chemical composition, mass%						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	cl
Natural raw materials							
Limestone of the Kazygurt deposit	4.86	0.72	0.81	51.75	0.36	0.02	41.12
Loess of the Tekesu deposit	50.54	10.35	4.43	13.91	2.67	0.21	13.06
Man-made raw materials that have undergone heat treatment							
Electrothermophosphorus slag (ETPS)	42.68	0.74	0.17	41.18	4.55	0.4	-
Clinker for the production of zinc ores from the Achisai plant	27.55	5.74	33.5	17.33	6.07	1.31	6.5
Man-made raw materials that have not been subjected to heat treatment							
Waste from crushing limestone from the Sastyubinskoye deposit	9.63	1.72	1.26	46.0	0.55	1.15	36.2
Waste from coal mining in the Lenger mines	55.50	10.60	2.01	3.21	0.70	0.79	24.08

In addition to the chemical composition of the raw material, its mineralogical composition is important, which affects the technological process, the firing of clinker and the properties of cement.

Limestone from the Kazygurt deposit (Shymkentcement LLC) contains about 82% calcite, is characterized by a high content of the clay mineral illite - 7.8%.

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In order to obtain composite cements, as well as to reduce the proportion of clinker in cement, clay shales were studied, which will be used as a mineral additive. Averaged samples were selected from the samples by quartering. Clay shales were studied using SEM, X-ray diffraction, DTA and spectroscopic methods.

Average chemical composition of materials, %: Clinker sample No. 4 (Table 3) SiO_2 -18; Al_2O_3 – 3; CaO – 55; Fe_2O_3/FeO – 3; Na_2O – 0.42; K_2O – 1.2; MgO – 1.5. Clay shale of the Mynaral deposit SiO_2 -71; Al_2O_3 – 10; CaO – 5; Fe_2O_3/FeO – 11; Na_2O – 2; K_2O – 0.5; MgO – 0.5, Clay shale of the Kuyuk deposit - SiO_2 -53; Al_2O_3 – 10; CaO – 5; Fe_2O_3/FeO – 11; Na_2O – 2; K_2O – 0.5; MgO – 0.5.

The study of clay shale from the Mynaral deposit as a mineral additive was carried out in accordance with the requirements of GOST 25094-2015, the chemical composition was determined according to GOST 5382-2019 [29, 30].

Findings/Discussion

At the initial stage of the experimental part, the main physical and chemical changes during the firing of clay shales at temperatures of 700-900 °C were studied (Figure 2).

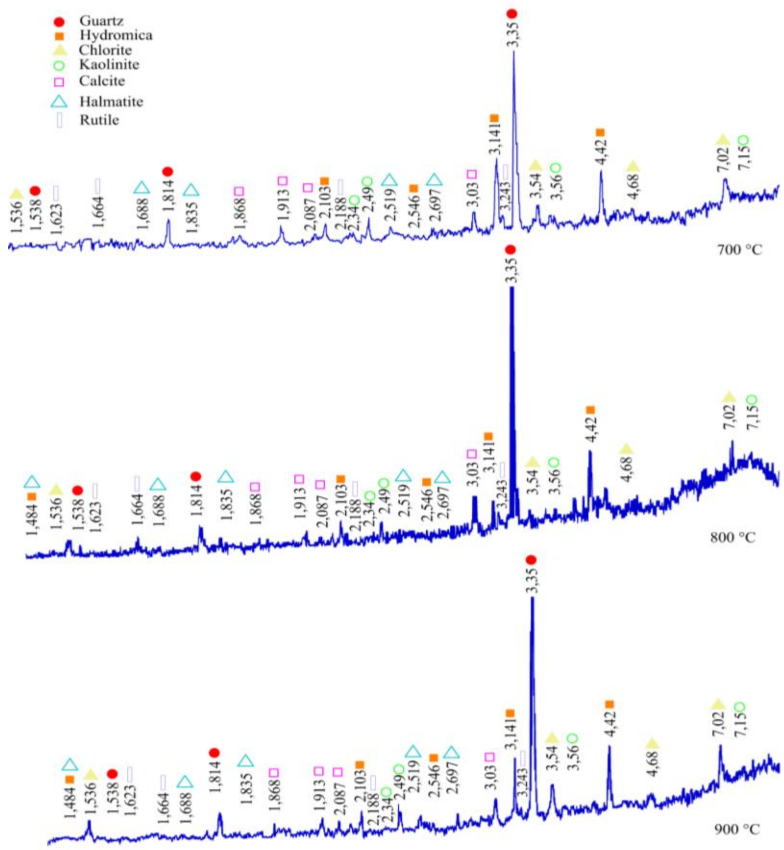


Figure 2. X-ray phase analysis of Mynaral shale fired at temperatures of 700-900 °C

On the X-ray diffraction pattern of clay shales (Figure 2), fired at a temperature of 700 °C, the diffraction maxima of the following minerals were recorded: α-quartz; hydromica; chlorite; kaolinite; calcite; hematite; rutile.

At 800 °C, the diffraction maxima of the following minerals were recorded: β-quartz; mica; chlorite; kaolinite; calcite; hematite; rutile.

At a firing temperature of 900 °C, the diffraction maxima of the following minerals were recorded: β-quartz; dehydrated mica; chlorite; kaolinite; calcite; hematite; rutile.

The study of the activity of the shale of the Mynaral deposit was carried out by the classical method of lime absorption from a lime solution. Figure 3 shows the dependence of the pozzolanic activity of Mynaral shales fired at 700, 800 and 900 °C.

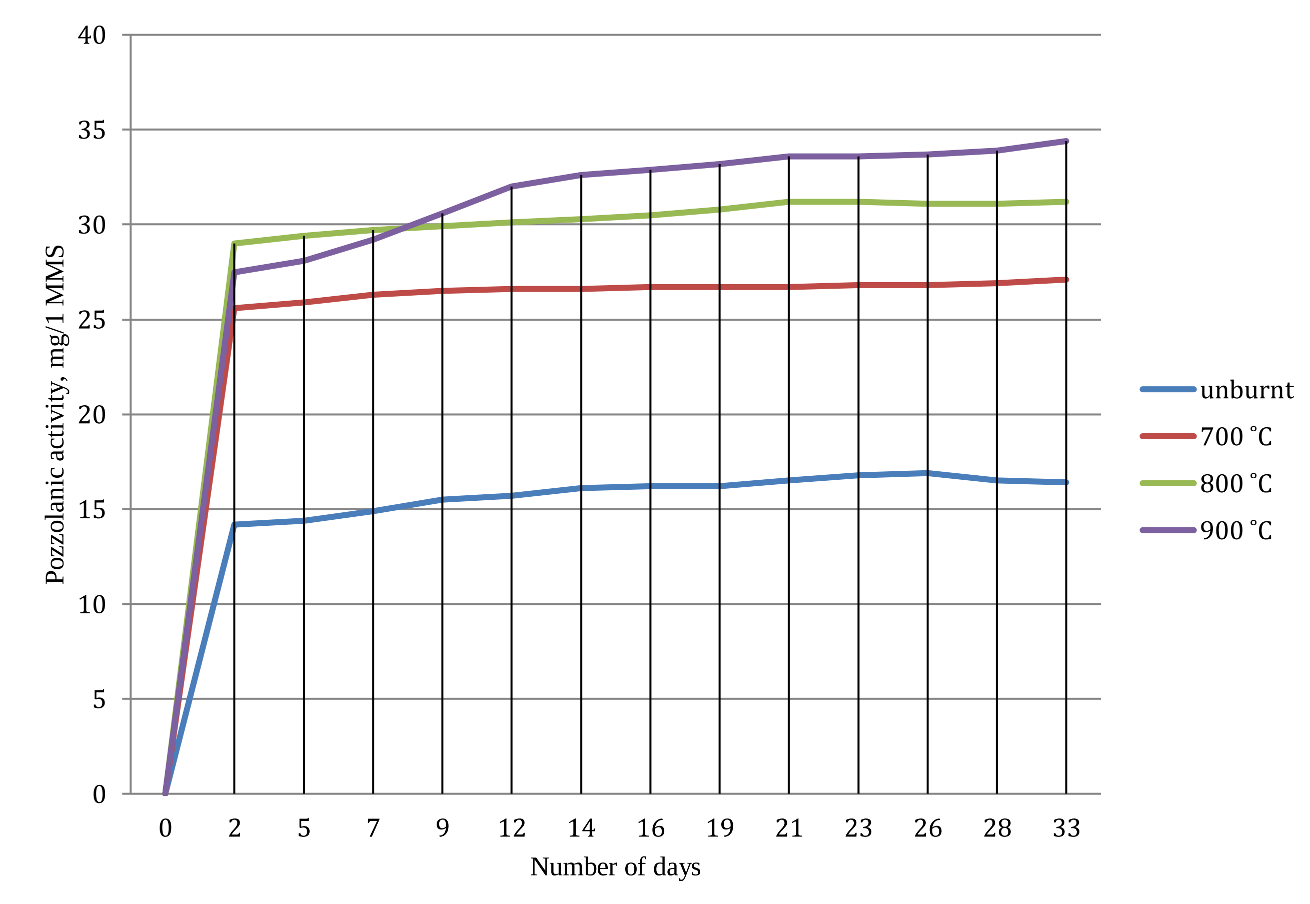


Figure 3. Dependence of the pozzolanic activity of Mynaral slate on the firing temperature

Analysis of the obtained data showed that firing parameters have different effects on the properties of additives, which is due to their chemical and mineralogical composition. Thus, when firing Mynaral slate at 800-900°C, an additive with maximum pozzolanic activity was obtained.

Our studies have shown the possibility of replacing natural raw materials for clinker production with industrial waste, which will reduce fuel consumption for clinker firing, increase furnace productivity, and reduce CO_2 emissions into the atmosphere [31-33]. The following waste and non-traditional raw materials are proposed for this purpose: coal mining waste from the Lenger coal mines, limestone crushing waste, lead slag from the Shymkent plant, clinker from the

Waelz zinc ore production at the Achisai plant, and tephrite basalt from the Daubabinskoye deposit.

Table 3 presents data on the effect of firing temperature and mixture compositions on the content of free CaO in cakes.

Table 3. Effect of mixture compositions and firing temperature on the firing process of low-energy clinkers

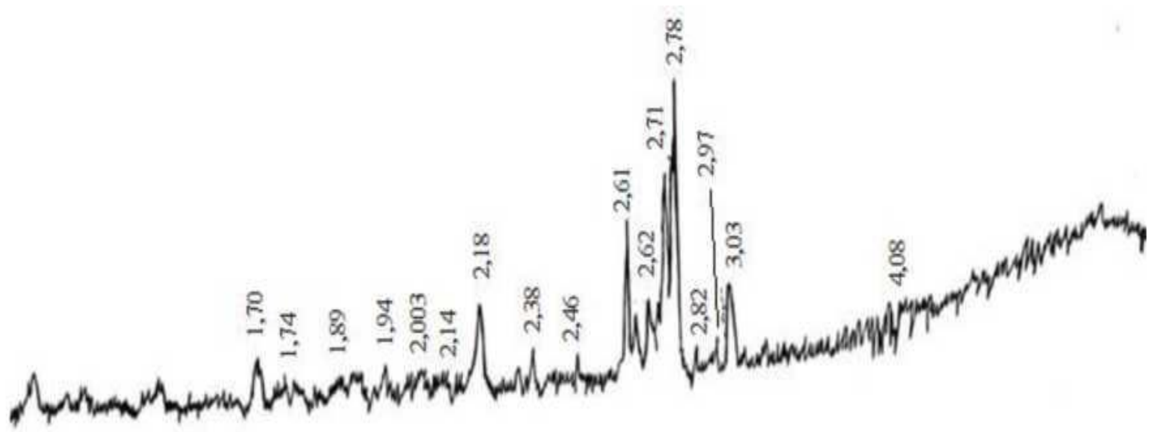
Mixture	Component composition of raw materials, wt.%						Modular characteristics			Content of free CaO, %, during firing, ^0C			
	Limestone	Coal mining waste	Cinders KN	Coal waste + tephrite-basalt (1:1)	Lead slag	Loess	KN	n	p	1300	1350	1400	1450
Control	78.2	-	1.5	-	-	20.3	0.90	2.4	1.68	8.63	6.36	3.52	1.68
1	78.12	18.91	2.97	-	-	-	0.92	2.4	1.08	10.21	5.37	3.28	1.48
2	76.94	18.02	-	-	5.04	-	0.90	2.4	1.14	5.93	1.73	1.29	0.97
3	77.37	17.67	-	-	4.96	-	0.92	2.4	1.14	7.13	1.63	1.53	1,26
4	75.14	-	-	22.17	2.69	-	0.85	2.4	1.26	2.23	0.94	0.57	0.35
5	76.39	-	-	21.37	2.24	-	0.90	2.4	1.26	2.52	1.38	1.08	0.68
6	75.33	-	-	18.31	6.36	-	0.92	2.2	0.84	1.17	1.03	0.62	0.28
7	76.79	-	-	20.68	2.53	-	0.92	2.4	1.27	2.78	1.78	1.26	0.75
8	77.45	-	-	20.11	2.44	-	0.95	2.4	1.27	3.81	1.86	1.41	0.87

The firing of the control limestone-loess raw mix is completed at 1450 ^oC. The introduction of about 5% lead slag has a significant mineralizing effect in batches No. 2 and 3. The content of unassimilated CaO at a temperature of 1350 ^oC decreases to 1.63-1.73%.

Raw mixes No. 4, 5, 7 and 8 contain 20-22% coal waste and 2.5-2.7% lead slag. Sufficiently complete assimilation of calcium oxide (1.39-1.85%) in these mixes is achieved at 1350 ^oC.

The value of the silicate modulus affects the amount of lead slag introduced. Thus, in raw mix No. 6, with a decrease in the silicate modulus to two, the introduction of lead slag increases to 6.25%. This leads to a significant acceleration of the clinker formation processes, a sufficiently complete assimilation of CaO into clinker minerals is completed at 1300 °C, which is 150 °C lower than in the control batch. In other experimental raw material batches with KH = 0.9 - 0.92, the clinker formation processes are completed at 1350 °C. The content of free CaO in clinkers is 0.93 - 1.74%, which meets the requirements of the plant's process regulations. The X-ray diffraction pattern of clinker is shown in Figure 4.

It was found that the clinker sintering process significantly depends on the lead slag content in the batch: an increase in the slag content accelerates the processes and reduces the clinker firing temperature. The results obtained indicate that it is possible to obtain low-energy clinkers at temperatures of 1300-1350 °C. This will lead to a decrease in fuel consumption for firing and savings in traditional raw materials for cement production.



d: 2.18; 2.61; 2.78; 3.03Å – C_3S; d=1.74; 1.94; 2.71; 2.82Å – C_2S; d=1.89; 2.82; 2.97; 4.08Å – C_3A; d=2.003; 2.14; 2.65Å – C_4AF.

Figure 4. X-ray phase analysis of clinker from raw material batch No. 2, fired at 1350^{0}C

The following main clinker minerals were identified in low-energy clinker No. 2: C_3S d = 2.18; 2.61; 2.78; 3.03Å; C_2S d = 1.74; 1.94; 2.71; 2.82Å; C_3A d = 1.89; 2.82; 2.97; 4.08Å; C_4AF d = 2.003; 2.14; 2.65Å (Figure 2). No noticeable peaks of other minerals were detected.

A micrograph from a chip of low-energy clinker No. 5 is shown in Figure 5. Analysis of the micrograph allows us to conclude that the crystallization of minerals is clear, their distribution is uneven. Along with areas where alite has a regular geometric shape, there are areas with an indefinite crystal shape.

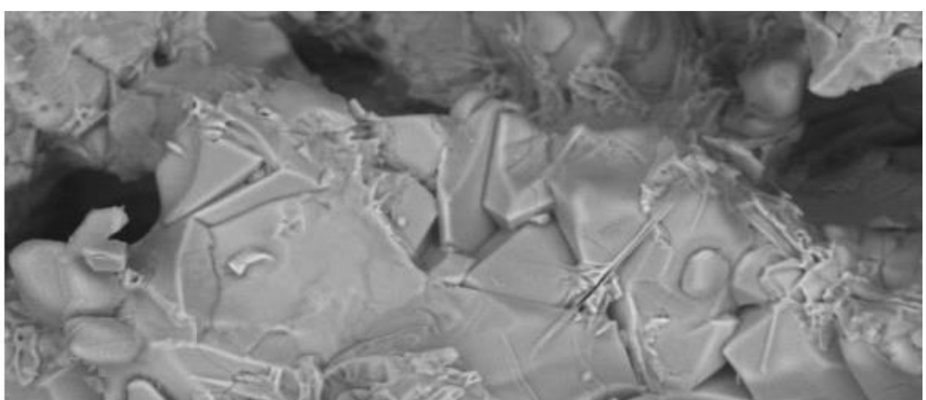


Figure 5. Micrograph of clinker from the raw material batch "limestone + (coal mining waste + tephrite basalt (1:1) + lead slag"

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Alite crystallized in the form of minerals of various sizes, sometimes quite large up to 100-140 microns. Lead slag together with tephrite basalt had a fairly strong mineralizing effect on firing, the temperature of the end of clinker sintering decreased from the traditional 1450 °C to 1350 °C, alite crystals grew to fairly large sizes, the residual content of CaO_{free} was 1.39%. Belite is represented by crystals of round and oval shape, cracks are observed on the surface of belite granules. The content of the intermediate phase is quite large and it is represented mainly by calcium aluminoferrite, which is represented by light needle-shaped crystals.

Our studies have also shown the possibility of energy-saving production of cement clinkers from raw mixes consisting entirely of industrial waste. In raw material batches containing 78.8-79.9% of Sastobe limestone crushing waste, 3.84-5.16% of zinc ore Waelz clinker, 15.2-17.3% of phosphorus slag, high-quality clinker can be obtained at 1350 °C. The content of free CaO in clinkers is 1.4-1.5%. Calcium fluoride in phosphorus slag, zinc oxide contained in Waelz clinker, lower the sintering temperature of clinker, accelerate mineral formation processes, and improve the clinker structure. Reducing the firing temperature and fuel consumption will reduce CO_2 and NOx emissions into the atmosphere, utilize man-made products and reduce the pressure on the environment. The optimal compositions of batches are with KH = 0.9-0.92.

According to the results of X-ray phase analysis, the following minerals are formed in the clinker synthesized at 1350 °C: alite (d =3.05; 2.7726; 2.595; 2.33; 2.172; 1.973; 1.757; 1.484 Å); belite (d=2.78; 2.758; 2.595; 2.425; 2.268; 2.172; 2.037; 1.973; 1.882 Å); C_4AF (d = 7.3224; 2.772; 2.678; 2.63 Å).

Microscopic analysis of the clinkers showed the formation of hexagonal and pentagonal alite crystals, rounded belite crystals. Crystallization of clinker minerals is clear and good. The size of alite crystals ranges from 20-30 to 40-60 microns.

Thus, in the process of firing cement clinkers, phosphorus and lead slag, zinc ore Waelz clinker, and tephrite basalt lead to the appearance of a liquid phase at low temperatures, improve its properties, have a mineralizing effect on firing, accelerate the formation of the main minerals belite and alite, facilitate the completion of clinker formation processes at temperatures 100°C lower than in traditional raw mixes, and accelerate the sintering process of clinker. The content of free CaO in low-energy clinkers fired at 1350°C is within the plant standard.

Another effective way to reduce carbon dioxide emissions into the atmosphere during cement production is to reduce the clinker component in cements by introducing active mineral additives.

We have conducted experiments on the use of fired shales from the Mynaral deposit and the Kuyuk deposit as additives to composite cements. In accordance with the requirements of GOST 310.4-81, samples without additives and with additives of shale from the Mynaral deposit and Kuyuk were molded after 3, 7 and 28 days, tested in a hydraulic press and strength indicators were established.

With the addition of 15% of clay shale from the Mynaral deposit, fired at 900 °C, the maximum value of the strength of the cement stone for 28 days was obtained - 50 MPa.

After completing the physical and mechanical tests of cements without additives and with additives of 5-15% of fired shale from the Mynaral deposit, a chemical analysis of the hydrated cement stone was carried out.

The chemical composition of the cement stone was determined using raster electron microscopic analysis. The presence of oxides P_2O_5, Cr_2O_3, BaO, TiO_2, Mn_2O_3 in the amount of 0.2-

0.5% in Portland cement in the form of solid solutions in clinker minerals leads to the acceleration of cement hydration and an increase in the strength of the cement stone. The formation of a strong structure of cement stone based on low-basic calcium hydrosilicates (CSH) contributes to an increase in its strength at the initial stage. The content of oxides in cement stones containing a mixture of shale without impurities and burnt clay is shown in the graph in Figure 6.

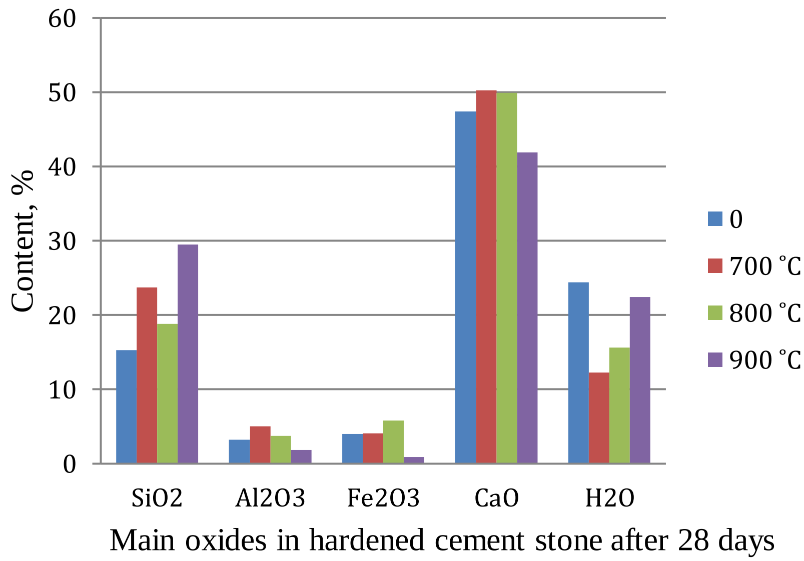

Figure 6. Oxide content in cement stone without additives and with additives of burnt clay shale from the Mynaral deposit

The following diffraction maxima were recorded in the X-ray diffraction patterns of the cement stone: portlandite - $Ca(OH)_2$, d / n: 4.92; 3.11; 2.63; 1.924; 1.791 Å; dicalcium hydrosilicate - C_2SH (B), d / n: 4.80; 2.94; 2.77; 2.26; 1.872 Å; dicalcium hydrosilicate - C_2SH (C), dicalcium hydrosilicate - C_2SH (A), d / n: 4.21; 3.28; 2.67; 2.42; 1.786 Å; d / n: 3.04; 2.84; 2.70; 1.909; 1.896 Å .

Burnt shale contains active silica and alumina oxide, which quickly react with cement minerals and their hydration products to form stable hydrate compounds. As a result, the strength of 3-day cement stone with 15% shale burned at 900 °C increases by 8% compared to cement stone without additives. The strength of cement stone with the addition of 10% shale burned at 800 °C at the age of 28 days increased by 10%. Clay shales burned at 700-900 °C react with minerals contained in cement, as well as with $Ca(OH)_2$ to form structured calcium hydrosilicates of the C_2SH (A), C_2SH (B) type, which have high water resistance and provide increased strength of cement stone.

Conclusion

Modern trends in the development of cement process technologies are: high unit capacity of the production line, informatization, digitalization of production management, intellectualization of cement equipment, energy saving of the production process and reduction of carbon dioxide emissions.

The chemical and mineralogical composition of industrial waste in Southern Kazakhstan and the possibility of using it to produce cement clinker have been established.

Low-energy compositions of raw material mixtures have been developed for producing Portland cement clinker, including limestone crushing waste, coal mining waste, lead and phosphorus slag, tephrite basalt and zinc ore Waelz clinker. These wastes replace from 20-25% to 100% of natural raw materials, allow completing clinker formation processes at 1300 - 1350°C, increasing furnace productivity and reducing harmful carbon dioxide emissions into the atmosphere by 15-20%. The processes of firing raw mixes consisting entirely or partially of industrial waste are completed at 1350°C. This will reduce the consumption of nozzle fuel for firing clinker, increase furnace productivity and reduce the volume of CO_2 emissions into the atmosphere.

High-quality cement clinker was obtained based on raw mixes with Waelz clinker of zinc ores of the Achisai Metallurgical Plant, phosphorus slag, coal mining waste of the Lenger mines and sodium fluoride. The phase composition and microstructure of low-energy clinkers were identified. Involvement of industrial waste in the raw material cycle will reduce environmental pollution and improve the environment.

By introducing additives of burnt shale from the Betpakdala deposit, it is possible to obtain composite cements with a decrease in the share of the clinker component by 10-15%, which will reduce harmful emissions of carbon dioxide into the atmosphere by the same amount. Research in this area will expand the raw material base of active mineral additives for the production of composite cements with low carbon dioxide emissions into the atmosphere.

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The contribution of the authors.

Baurzhan Amiraliyev– concept, resources, supervision, analysis, resources, drafting, editing.
Taimasov Bakhytzhan – data collection, testing, concept, methodology.
Куандыкова Акнур – funding acquisition, drafting, editing.
Potapova Ekaterina – methodology, drafting, interpretation.
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References

1. Taimasov B.T., Klassen V.K. *Khimicheskaya tekhnologiya vyazhushchikh materialov* [Chemical technology of binders]: textbook/ -2nd edition, suppl. - Belgorod: Publishing house of BSTU, 2017. - 448 p. https://jcement.ru/reading/books/b-t-taymasov-v-k-klassen-khimicheskaya-tekhnologiya-vyazhushchikh-materialov/

2. Klassen V.K. Taimasov B.T. *Tsementologiya: struktura, svoystva tsementov i optimizatsiya tekhnologicheskikh protsessov* [Cementology: structure, properties of cements and optimization of technological processes]: textbook / V.K. Klassen, B.T. Taimasov. - Moscow; Vologda: Infra-Engineering, 2024. – 264p. https://www.litres.ru/book/b-t-taymasov/cementologiya-struktura-svoystva-cementov-i-optimizaciya-tehn-70883365/
3. Taimasov B.T.: textbook / B.T. Taimasov. Tehnologiya proizvodstva portlandcementa - Almaty: Evero, 2015. - 272 c. [Technology of Portland cement production] https://thelib.net/1712136-tehnologija-proizvodstva-portlandcementa.html
4. Klassen, V.K. / V.K. Klassen, I.N. Borisov, V.E. Manuilov. Tehnogennie materiali v proizvodstve cementa - Belgorod: Izd-vo BSTU, 2008. - 126 p. [Technogenic materials in cement production: monograph] https://search.rsl.ru/ru/record/01004343586
5. Luis M. Romeo, David Catalina, PilarLisbona, Yolanda Lara, Ana Martinez., 2021 — Luis M. Romeo, David Catalina, PilarLisbona, Yolanda Lara, Ana Martinez. Reduction of greenhouse gas emissions by integration of cement plants, power plants, and CO_2 capture systems, Greenhouse Gases: Science and Technology, 1:1:72-82. DOI:10.1002/ghg3.5 https://scholar.google.bg/citations?user=_7rUOIUAAAAJ&hl=tr
6. Ozerova E.M., Kaigorodov O.N., Ispolzovanie othodov v Rossiiskoi cementnoi promishlennosti 2020. №4. - p.33-35. [Waste utilisation in the Russian cement industry // Cement and its application] https://jcement.ru/magazine/vypusk-4-2020/ispolzovanie-otkhodov-v-rossiyskoy-tsementnoy-promyshlennosti/
7. M.I. Sanche de Rojas, A. Asencio, M. Frias, I. Cuevas, C. Nizkoklinkernie cementi_ soderjaschie stroitelnie othodi i lom kak puccolanovuyu dobavku // Cement and its applications, 2020. №2. - p. 84-89. [Medina Low clinker cements containing construction waste and scrap as pozzolanic additive] https://jcement.ru/magazine/vypusk-2-2020/nizkoklinkernye-tsementy-soderzhashchie-stroitelnye-otkhody-i-lom-kak-putstsolanovuyu-dobavku/
8. Abramson I. G. / I. G. Abramson Problemi i perspektivi ustoichivogo razvitiya industrii osnovnih stroitelnih materialov // Cement and its application. - 2007. №6. - p.123-128. [Problems and prospects of sustainable development of the basic building materials industry] https://jcement.ru/magazine/vypusk-6-239/problemy-i-perspektivy-ustoychivogo-razvitiya-industrii-osnovnykh-stroitelnykh-materialov/
9. M. Fantini, M. Spinelli, F. Malli, M. Gatti, S. Proekt CLEANKER_ ulavlivanie SO_2 v cementnoi promishlennosti // Cement and its applications, 2020. №2. - p.78-80. [Consonni Project CLEANKER: CO_2 capture in the cement industry] https://jcement.ru/magazine/vypusk-2-2020/proekt-cleanker-ulavlivanie-co-v-tsementnoy-promyshlennosti/
10. Sanatov A. / A. Sanatov, S. Estai, T. Khakimzhanov Analiz sostoyaniya vibrosov parnikovih gazov // Industry of Kazakhstan. - 2010. - №5. - p. 49-51. [Analysis of the state of greenhouse gas emissions]. https://studylib.ru/doc/4430389/sanatova-t.-s.--amrenova-a.zh.---g
11. Magistri M. Clinker savings using additives / M. Magistri, P. D'Arcangelo. // International Cement Review. – 2009. – №2. – P. 102–106.https://cadd.mapei.com/wp-content/uploads/2023/11/The-challenge-of-low-clinker-cements-Ibausil-September-2023.pdf
12. Taimasov B.T., Khudyakova T.M., Zhanikulov N.N. Kompleksnoe ispolzovanie prirodnogo i tehnogennogo sirya v proizvodstve maloenergoemkih cementov. Shymkent: Typography

ISSN: 2616-7263. eISSN: 2663-1261

‘Alem’, 2017. – 200p. [Integrated use of natural and man-made raw materials in the production of low-energy cement] https://auezov.edu.kz/images/files/%D0%9D%D0%A2_2021/%D0%9D%D0%A2%201%202021.pdf

13. Taimasov B.T., Dauletiyarov M.S., Zhanikulov N.N., Kassimbekov T.A., Kuandykova A.E. et al. Patent of the Republic of Kazakhstan No. 36495 for invention under application No. 2022/0538.1 "Raw material mixture for producing Portland cement clinker". 08.12.2023.
14. Kuandykova, B. Taimasov, N. Zhanikulov, E. Potapova. *Belïtti klïnker sïntezdew üşin aşçisay metallwrgïyalı zawıtınıñ klïnkerin qoldanw* [Use of clinker from the Ashchisai Metallurgical Plant for the synthesis of Belite clinker Series] // News of the National Academy of Sciences of the Republic of Kazakhstan. Series CHEMISTRY AND TECHNOLOGY 1 (458) January – March 2024 ALMATY, NAS RK - P.83-93. https://journals.nauka-nanrk.kz/chemistry-technology/article/view/6081/4371
15. Sivkov S.P., Korchunov I.V., Potapova E.N., Dmitrieva E.A., Klimenko,N.N. Activity Thermodynamics of Compounds in Carbonation-Hydration Hardening Cements// Glass and Ceramics. 2023. V. 79. № 9-10. P. 371-377. https://www.researchgate.net/publication/368965373_Activity_Thermodynamics_of_Compounds_in_Carbonation-Hydration_Hardening_Cements
16. Smolskaya E.A. Potapova E.N., Korshunov I.V., Sivkov S.P. Properties of geopolymer cement based on thermally activated clay// Cement and its application. 2024. No. 1.pp. 50-54. https://jcement.ru/magazine/vypusk-1-2024/svoystva-geopolimernogo-tsementa-na-osnove-termoaktivirovannykh-glin/ (circulation date: 23.05.2024). https://doi.org/10.61907/CIA.2024.82.52.001
17. Ram K.; Flegar M.; Serdar M.; Scrivener, K. Influence of Low- to Medium-Kaolinite Clay on the Durability of Limestone Calcined Clay Cement (LC3) Concrete.Materials 2023, 16, 374. https://doi.org/10.3390/ma16010374
18. Yang Dan, Wu Zude, Xie Jianfeng, Taimasov B.T., et al. *Novyye tekhnologii i tendentsii razvitiya tsementnogo proizvodstva i oborudovaniya* [New technologies and trends in the development of cement production and equipment]: textbook. - Shymkent: M. Auezov South Kazakhstan University, 2024. - 580 p. https://auezov.edu.kz/rus/%D1%8D%D0%BB%D0%B5%D0%BA%D1%82%D1%80%D0%BE%D0%BD%D0%BD%D1%8B%D0%B5-%D0%BA%D0%BD%D0%B8%D0%B3%D0%B8/429/all_category
19. *Opredeleny tovary s obyazatel'nym ispol'zovaniyem vtorsyr'ya s 2025 goda* [Products with mandatory use of recycled materials from 2025 have been identified] // [*Tsement i yego primeneniye* Cement and its application] Date of access: 03.09.2024. https://jcement.ru/content/news/opredeleny-tovary-s-obyazatelnym-ispolzovaniem-vtorsyrya-s-2025-goda/
20. *Strany G20 namereny prekratit' vybrosy parnikovykh gazov k seredine XXI veka*]. [G20 countries intend to stop greenhouse gas emissions by the middle of the 21st century // *Tsement i yego primeneniye* [Cement and its application]. Date of acces: 31.10.2021. https://www.vedomosti.ru/society/news/2021/10/31/893799-strani-g20
21. *Heidelberg Cement zapuskayet pilotnyy proyekt po ulavlivaniyu* CO_2 [Heidelberg Cement launches pilot project for CO_2 capture] // *Tsement i yego primeneniye* [Cement and its

application]. Date of 17.09.2021. https://jcement.ru/content/news/heidelbergcement-zapuskaet-pilotnyy-proekt-po-ulavlivaniyu-so2/

22. *V Uzbekistane izuchayut vliyaniye promyshlennykh predpriyatiy na ekologiyu* [In Uzbekistan, the impact of industrial enterprises on the environment is being studied] // *Tsement i yego primeneniye* [Cement and its application]. Date of access: 08.11.2023. https://jcement.ru/content/news/v-uzbekistane-izuchayut-vliyanie-promyshlennykh-predpriyatiy-na-ekologiyu/
23. https://jcement.ru/content/news/heidelberg-materials-predstavila-evozero-pervyy-v-mire-tsement-s-nulevym-uglerodnym-sledom/ 1/1 28.11.2023.
24. *Kompaniya Aggregate Industries ispol'zuyet otkhody proizvodstva keramicheskikh plit.* [Aggregate Industries uses waste from ceramic tile production]. Source: Aggregate Industries. Great Britain. Date of access: 23.11.2023. https://jcement.ru/content/news/kompaniya-aggregate-industries-ispolzuet-otkhody-proizvodstva-keramicheskikh-plit/
25. GOST 5382-2019. Cements and cement production materials. Methods of chemical analysis. Izd-v Standardinform. - Moscow. 2019. - 30 c. Date of introduction 01.06.2020.
26. Taimasov B.T., / B.T. Taimasov, T.M. Khudyakova, M.S. Dauletiyarov. Fiziko_himicheskie metodi analiza vyajuschih materialov - Moscow; Vologda : Infra-Engineering, 2024. 144 p. [Physico-chemical methods of analysing binding materials: a practical manual] https://www.labirint.ru/books/997158
27. Gorshkov V.S., Timashev V.V., Metodi fiziko_himicheskogo analiza vyajuschih veschestv: Textbook. - Moscow: Higher School, 1981. – 335p. [Savelyev V.G. Methods of physico-chemical analysis of binding agents] https://www.twirpx.com/file/177095/
28. Myrzakozha D., Mirzakhodzhaev A.A.: Sovremennie metodi issledovaniya Textbook. 4th ed., supplement. Almaty: 2013. - 428p. [Modern methods of research] https://omarket.kz/catalog/ecc_dosug_knigi/ecc_Knigi/textbooks-and-manuals/uchebnoe-posobie-d-myrzaozha-sovremennye-metody-issledovaniya.html
29. GOST 25094-2015 Active mineral additives for cements. Method for determination of activity. Standard Inform Publishing House: Moscow, Russia, 2016.
30. GOST 5382-2019 Cements and cement production materials. Methods of chemical analysis. Standard Inform Publishing House: Moscow, Russia, 2019.
31. Zhanikulov N.N. Research on obtaining low energy cements from technogenic raw materials / N.N. Zhanikulov, B.T. Taimasov, I.N. Borisov, Zh.K. Dzhanmuldaeva, M.S. Dauletiarov. // Journal of Chemical Technology and Metallurgy. - Bulgaria. - 2020. Vol. 55, №4. - P. 814-823.https://journal.uctm.edu/node/j2020-4/19_19-191_p_814-823.pdf
32. Taimasov B.T. Development and Testing of Low-Energy-Intensive Technology of Receiving Sulphate-Resistant and Road Portlandcement / B.T. Taimasov, B.K. Sarsenbayev, T.M. Khydyakova, A.S. Kolesnikov, N.N. Zhanikulov. // Eurasian Chemico-Technological Journal. - 2017. - Vol. 19, № 4. - P.347-355.https://ect-journal.kz/index.php/ectj/article/view/78
33. Taimasov B.T. *Protsessy klinkeroobrazovaniya v maloenergoyemkikh syr'yevykh shikhtakh* [Clinker formation processes in low-energy raw material batches] / B.T. Taimassov, T.M. Khudyakova, N.N. Zhanikulov, A.N. Khashimov // Cement and its application [*Tsement i yego primeneniye*]. - 2018. - No. 1. -P.170-174. https://jcement.ru/magazine/vypusk-1-504/protsessy-klinkeroobrazovaniya-v-maloenergoemkikh-syrevykh-shikhtakh/

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Современные тенденции развития цементного производства

Аннотация. Рассмотрена возможность получения портландцементного клинкера с использованием малоэнергоемких, ресурсосберегающих технологий. Установлен химический и минералогический состав крупнотоннажных отходов промышленности для малоэнергоемкого получения портландцементного клинкера на заводах Южного Казахстана. Показана возможность замены дефицитной железосодержащей корректирующей добавки клинкером вельцевания цинковых руд. При этом клинкер вельцевания в составе сырьевой шихты выполняет несколько задач: является железистой корректирующей добавкой, работает как минерализатор процессов клинкерообразования, вносит в шихту уголь и позволяет снизить расход природного топлива. Это будет способствовать снижению расхода форсуночного топлива на обжиг клинкера и уменьшению выбросов CO_2 в атмосферу. Установлена возможность получения портландцементного клинкера на основе отходов промышленности из разработанных малоэнергоемких ресурсосберегающих сырьевых смесей с клинкером вельцевания цинковых руд Ачисайского металлургического завода, фосфорным шлаком, отходами угледобычи ленгерских шахт и фтористым натрием. Применение добавок обожженных сланцев месторождения Бетпакдала для получения композиционных цементов со снижением доли клинкерной составляющей на 10-15 % и утилизация крупнотоннажных отходов промышленности позволит снизить загрязнение окружающей среды и улучшить экологическую обстановку в регионе.

Ключевые слова: цементный клинкер, обжиг, отходы, клинкер вельцевания цинковых руд, расход топлива, композиционный цемент.

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Аңдатпа. Портландцементті Клинкерді аз энергияны қажет ететін, ресурстарды үнемдейтін технологияларды қолдану арқылы алу мүмкіндігі қарастырылған. Оңтүстік Қазақстан зауыттарында портландцементті Клинкерді аз энергияны қажет ететін алу үшін ірі тоннажды өнеркәсіп қалдықтарының химиялық және минералогиялық құрамы белгіленді. Құрамында темірі бар жетіспейтін түзету қоспасын мырыш кендерін илеу клинкерімен алмастыру мүмкіндігі көрсетілген. Сонымен қатар, шикізат шихтасының құрамындағы клинкер бірнеше тапсырмаларды орындайды: бұл безді түзету қоспасы, клинкер түзілу процестерінің минерализаторы ретінде жұмыс істейді, шихтаға көмір енгізеді және табиғи отын шығынын азайтуға мүмкіндік береді. Бұл Клинкерді жағу үшін инжекторлық отын шығынын азайтуға және атмосфераға CO_2 шығарындыларын азайтуға көмектеседі. Ачисай металлургиялық зауытының мырыш кендерін илеу клинкерімен, фосфор қожымен, Ленгер шахталарының көмір өндіру қалдықтарымен және натрий фторидімен әзірленген аз энергияны қажет ететін ресурс үнемдейтін шикізат қоспаларынан өнеркәсіп қалдықтары негізінде портландцемент клинкерін алу мүмкіндігі белгіленді. Клинкер құрамдас бөлігінің үлесін 10-15% - ға төмендете отырып, композициялық цементтер алу үшін Бетпақдала кен орнының күйдірілген тақтатас қоспаларын қолдану және өнеркәсіптің ірі тонналық қалдықтарын кәдеге жарату қоршаған ортаның ластануын азайтуға және өңірдегі экологиялық жағдайды жақсартуға мүмкіндік береді.

Түйін сөздер: цемент клинкері, күйдіру, қалдықтар, мырыш кендерін илеу клинкері, отын шығыны, композициялық цемент.

References

1. Taimasov B.T., Klassen V.K. *Khimicheskaya tekhnologiya vyazhushchikh materialov* [Chemical technology of binders]: textbook/ -2nd edition, suppl. - Belgorod: Publishing house of BSTU, 2017. - 448 p. https://jcement.ru/reading/books/b-t-taymasov-v-k-klassen-khimicheskaya-tekhnologiya-vyazhushchikh-materialov/
2. Klassen V.K. Taimasov B.T. *Tsementologiya: struktura, svoystva tsementov i optimizatsiya tekhnologicheskikh protsessov* [Cementology: structure, properties of cements and optimization of technological processes]: textbook / V.K. Klassen, B.T. Taimasov. - Moscow; Vologda: Infra-Engineering, 2024. – 264p. https://www.litres.ru/book/b-t-taymasov/cementologiya-struktura-svoystva-cementov-i-optimizaciya-tehn-70883365/
3. Taimasov B.T.: textbook / B.T. Taimasov. Tehnologiya proizvodstva portlandcementa - Almaty: Evero, 2015. - 272 с. [Technology of Portland cement production] https://thelib.net/1712136-tehnologija-proizvodstva-portlandcementa.html
4. Klassen, V.K. / V.K. Klassen, I.N. Borisov, V.E. Manuilov. Tehnogennie materiali v proizvodstve cementa - Belgorod: Izd-vo BSTU, 2008. - 126 p. [Technogenic materials in cement production: monograph] https://search.rsl.ru/ru/record/01004343586
5. Luis M. Romeo, David Catalina, PilarLisbona, Yolanda Lara, Ana Martinez., 2021 — Luis M. Romeo, David Catalina, PilarLisbona, Yolanda Lara, Ana Martinez. Reduction of greenhouse gas emissions by integration of cement plants, power plants, and CO_2 capture systems, Greenhouse Gases: Science and Technology, 1:1:72-82. DOI:10.1002/ghg3.5 https://scholar.google.bg/citations?user=_7rUOIUAAAAJ&hl=tr
6. Ozerova E.M., Kaigorodov O.N., Ispolzovanie othodov v Rossiiskoi cementnoi promishlennosti 2020. №4. - p.33-35. [Waste utilisation in the Russian cement industry // Cement and its application] https://jcement.ru/magazine/vypusk-4-2020/ispolzovanie-otkhodov-v-rossiyskoy-tsementnoy-promyshlennosti/
7. M.I. Sanche de Rojas, A. Asencio, M. Frias, I. Cuevas, C. Nizkoklinkernie cementi_ soderjaschie stroitelnie othodi i lom kak puccolanovuyu dobavku // Cement and its applications, 2020. №2. - p. 84-89. [Medina Low clinker cements containing construction

waste and scrap as pozzolanic additive] https://jcement.ru/magazine/vypusk-2-2020/nizkoklinkernye-tsementy-soderzhashchie-stroitelnye-otkhody-i-lom-kak-putstsolanovuyu-dobavku/

8. Abramson I. G. / I. G. Abramson Problemi i perspektivi ustoichivogo razvitiya industrii osnovnih stroitelnih materialov // Cement and its application. - 2007. №6. - p.123-128. [Problems and prospects of sustainable development of the basic building materials industry] https://jcement.ru/magazine/vypusk-6-239/problemy-i-perspektivy-ustoychivogo-razvitiya-industrii-osnovnykh-stroitelnykh-materialov/
9. M. Fantini, M. Spinelli, F. Malli, M. Gatti, S. Proekt CLEANKER_ ulavlivanie SO_2 v cementnoi promishlennosti // Cement and its applications, 2020. №2. - p.78-80. [Consonni Project CLEANKER: CO_2 capture in the cement industry] https://jcement.ru/magazine/vypusk-2-2020/proekt-cleanker-ulavlivanie-co-v-tsementnoy-promyshlennosti/
10. Sanatov A. / A. Sanatov, S. Estai, T. Khakimzhanov Analiz sostoyaniya vibrosov parnikovih gazov // Industry of Kazakhstan. - 2010. - №5. - p. 49-51. [Analysis of the state of greenhouse gas emissions]. https://studylib.ru/doc/4430389/sanatova-t.-s.--amrenova-a.zh.---g
11. Magistri M. Clinker savings using additives / M. Magistri, P. D'Arcangelo. // International Cement Review. – 2009. – №2. – P. 102–106.https://cadd.mapei.com/wp-content/uploads/2023/11/The-challenge-of-low-clinker-cements-Ibausil-September-2023.pdf
12. Taimasov B.T., Khudyakova T.M., Zhanikulov N.N. Kompleksnoe ispolzovanie prirodnogo i tehnogennogo sirya v proizvodstve maloenergoemkih cementov. Shymkent: Typography ‘Alem’, 2017. – 200p. [Integrated use of natural and man-made raw materials in the production of low-energy cement] https://auezov.edu.kz/images/files/%D0%9D%D0%A2_2021/%D0%9D%D0%A2%201%202021.pdf
13. Taimasov B.T., Dauletiyarov M.S., Zhanikulov N.N., Kassimbekov T.A., Kuandykova A.E. et al. Patent of the Republic of Kazakhstan No. 36495 for invention under application No. 2022/0538.1 "Raw material mixture for producing Portland cement clinker". 08.12.2023.
14. Kuandykova, B. Taimasov, N. Zhanikulov, E. Potapova. *Belïtti klïnker sïntezdew üşin aşçïsay metallwrgïyalı zawıtınıñ klïnkerin qoldanw* [Use of clinker from the Ashchisai Metallurgical Plant for the synthesis of Belite clinker Series] // News of the National Academy of Sciences of the Republic of Kazakhstan. Series CHEMISTRY AND TECHNOLOGY 1 (458) January – March 2024 ALMATY, NAS RK - P.83-93. https://journals.nauka-nanrk.kz/chemistry-technology/article/view/6081/4371
15. Sivkov S.P., Korchunov I.V., Potapova E.N., Dmitrieva E.A., Klimenko,N.N. Activity Thermodynamics of Compounds in Carbonation-Hydration Hardening Cements// Glass and Ceramics. 2023. V. 79. № 9-10. P. 371-377. https://www.researchgate.net/publication/368965373_Activity_Thermodynamics_of_Compounds_in_Carbonation-Hydration_Hardening_Cements
16. Smolskaya E.A. Potapova E.N., Korshunov I.V., Sivkov S.P. Properties of geopolymer cement based on thermally activated clay// Cement and its application. 2024. No. 1.pp. 50-54. https://jcement.ru/magazine/vypusk-1-2024/svoystva-geopolimernogo-tsementa-na-

osnove-termoaktivirovannykh-glin/ (circulation date: 23.05.2024). https://doi.org/10.61907/CIA.2024.82.52.001

17. Ram K.; Flegar M.; Serdar M.; Scrivener, K. Influence of Low- to Medium-Kaolinite Clay on the Durability of Limestone Calcined Clay Cement (LC3) Concrete.Materials 2023, 16, 374. https://doi.org/10.3390/ma16010374
18. Yang Dan, Wu Zude, Xie Jianfeng, Taimasov B.T., et al. *Novyye tekhnologii i tendentsii razvitiya tsementnogo proizvodstva i oborudovaniya* [New technologies and trends in the development of cement production and equipment]: textbook. - Shymkent: M. Auezov South Kazakhstan University, 2024. - 580 p. https://auezov.edu.kz/rus/%D1%8D%D0%BB%D0%B5%D0%BA%D1%82%D1%80%D0%BE%D0%BD%D0%BD%D1%8B%D0%B5-%D0%BA%D0%BD%D0%B8%D0%B3%D0%B8/429/all_category
19. *Opredeleny tovary s obyazatel'nym ispol'zovaniyem vtorsyr'ya s 2025 goda* [Products with mandatory use of recycled materials from 2025 have been identified] // [*Tsement i yego primeneniye* Cement and its application] Date of access: 03.09.2024. https://jcement.ru/content/news/opredeleny-tovary-s-obyazatelnym-ispolzovaniem-vtorsyrya-s-2025-goda/
20. *Strany G20 namereny prekratit' vybrosy parnikovykh gazov k seredine XXI veka*]. [G20 countries intend to stop greenhouse gas emissions by the middle of the 21st century // *Tsement i yego primeneniye* [Cement and its application]. Date of acces: 31.10.2021. https://www.vedomosti.ru/society/news/2021/10/31/893799-strani-g20
21. *Heidelberg Cement zapuskayet pilotnyy proyekt po ulavlivaniyu CO_2* [Heidelberg Cement launches pilot project for CO_2 capture] // *Tsement i yego primeneniye* [Cement and its application]. Date of 17.09.2021. https://jcement.ru/content/news/heidelbergcement-zapuskaet-pilotnyy-proekt-po-ulavlivaniyu-so2/
22. *V Uzbekistane izuchayut vliyaniye promyshlennykh predpriyatiy na ekologiyu* [In Uzbekistan, the impact of industrial enterprises on the environment is being studied] // *Tsement i yego primeneniye* [Cement and its application]. Date of access: 08.11.2023. https://jcement.ru/content/news/v-uzbekistane-izuchayut-vliyanie-promyshlennykh-predpriyatiy-na-ekologiyu/
23. https://jcement.ru/content/news/heidelberg-materials-predstavila-evozero-pervyy-v-mire-tsement-s-nulevym-uglerodnym-sledom/ 1/1 28.11.2023.
24. *Kompaniya Aggregate Industries ispol'zuyet otkhody proizvodstva keramicheskikh plit.* [Aggregate Industries uses waste from ceramic tile production]. Source: Aggregate Industries. Great Britain. Date of access: 23.11.2023. https://jcement.ru/content/news/kompaniya-aggregate-industries-ispolzuet-otkhody-proizvodstva-keramicheskikh-plit/
25. GOST 5382-2019. Cements and cement production materials. Methods of chemical analysis. Izd-v Standardinform. - Moscow. 2019. - 30 c. Date of introduction 01.06.2020.
26. Taimasov B.T., / B.T. Taimasov, T.M. Khudyakova, M.S. Dauletiyarov. Fiziko_himicheskie metodi analiza vyajuschih materialov - Moscow; Vologda : Infra-Engineering, 2024. 144 p. [Physico-chemical methods of analysing binding materials: a practical manual] https://www.labirint.ru/books/997158

27. Gorshkov V.S., Timashev V.V., Metodi fiziko_himicheskogo analiza vyajuschih veschestv: Textbook. - Moscow: Higher School, 1981. – 335p. [Savelyev V.G. Methods of physico-chemical analysis of binding agents] https://www.twirpx.com/file/177095/
28. Myrzakozha D., Mirzakhodzhaev A.A.: Sovremennie metodi issledovaniya Textbook. 4th ed., supplement. Almaty: 2013. - 428p. [Modern methods of research] https://omarket.kz/catalog/ecc_dosug_knigi/ecc_Knigi/textbooks-and-manuals/uchebnoe-posobie-d-myrzaozha-sovremennye-metody-issledovaniya.html
29. GOST 25094-2015 Active mineral additives for cements. Method for determination of activity. Standard Inform Publishing House: Moscow, Russia, 2016.
30. GOST 5382-2019 Cements and cement production materials. Methods of chemical analysis. Standard Inform Publishing House: Moscow, Russia, 2019.
31. Zhanikulov N.N. Research on obtaining low energy cements from technogenic raw materials / N.N. Zhanikulov, B.T. Taimasov, I.N. Borisov, Zh.K. Dzhanmuldaeva, M.S. Dauletiarov. // Journal of Chemical Technology and Metallurgy. - Bulgaria. - 2020. Vol. 55, №4. - P. 814-823.https://journal.uctm.edu/node/j2020-4/19_19-191_p_814-823.pdf
32. Taimasov B.T. Development and Testing of Low-Energy-Intensive Technology of Receiving Sulphate-Resistant and Road Portlandcement / B.T. Taimasov, B.K. Sarsenbayev, T.M. Khydyakova, A.S. Kolesnikov, N.N. Zhanikulov. // Eurasian Chemico-Technological Journal. - 2017. - Vol. 19, № 4. - P.347-355.https://ect-journal.kz/index.php/ectj/article/view/78
33. Taimasov B.T. *Protsessy klinkeroobrazovaniya v maloenergoyemkikh syr'yevykh shikhtakh* [Clinker formation processes in low-energy raw material batches] / B.T. Taimassov, T.M. Khudyakova, N.N. Zhanikulov, A.N. Khashimov // Cement and its application [*Tsement i yego primeneniye*]. - 2018. - No. 1. -P.170-174. https://jcement.ru/magazine/vypusk-1-504/protsessy-klinkeroobrazovaniya-v-maloenergoemkikh-syrevykh-shikhtakh/

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