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Utilization of Natural Silicate Rocks to Reduce the Carbon Footprint in the Cement Industry

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ABSTRACT

Portland cement production is associated with high energy consumption and CO_2 emissions, highlighting the need for alternative raw materials to improve environmental sustainability. Research findings indicate that porphyrite, a natural silicate rock, exhibits pozzolanic and hydraulic activity, making it a promising additive in composite cement production. In this study, the physicochemical properties and hydration processes of porphyrite-modified Portland cement were analyzed using X-ray diffraction (XRD), differential thermal analysis (DSC), and Fourier-transform infrared spectroscopy (FTIR). The compressive strength and setting time of cement samples were tested according to GOST 30744-2001 and GOST 310-91 standards. The results showed that porphyrite addition slightly slowed the hydration process, reducing C_3S content while promoting the formation of calcium hydroxide ($Ca(OH)_2$). Cement containing 20% porphyrite met the 32.5N strength class requirements and demonstrated stable mechanical properties. Water absorption tests confirmed a gradual hydration process, with no sudden crystallohydrate formation observed. This study confirms that porphyrite is an effective mineral additive, contributing to cement durability, reduced clinker consumption, and lower energy demand. Future research should focus on the long-term stability of porphyrite-based cement using advanced thermal analysis techniques.

Keywords: Pozzolanic activity, hydration process, calcium hydroxide ($Ca(OH)_2$), physicochemical properties, X-ray diffraction (XRD), differential thermal analysis (DSC).

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Introduction

In modern construction materials manufacturing, one of the pressing tasks is to improve the Portland cement production process and reduce its environmental impact. In traditional cement manufacturing, a significant amount of natural resources is consumed for clinker production, and during the thermal decomposition of carbonate raw materials, a large volume of CO_2 is released into the atmosphere. Studies show that CO_2 emissions from cement production account for approximately 7-8% of total industrial emissions [[1], [2]]. In this regard, extensive scientific research is being conducted to enhance the environmental sustainability of the cement industry and reduce its carbon footprint [[3], [4]].

The prospects for producing composite Portland cement using alternative mineral components are attracting the attention of researchers. In particular, it has been proven that the incorporation of natural and industrial mineral additives—such as silicate rocks, volcanic ash-based materials, and industrial by-products—improves the physical and mechanical properties of cement [[5], [6]]. For instance, studies conducted by Gartner et al. demonstrated that adding silicon oxide-rich components to the cement composition not only preserves strength but also significantly reduces CO_2 emissions by decreasing the clinker content [[7], [8], [9], [10]].

Scrivener and co-authors studied technological solutions for the production of low-carbon cement and analyzed the effect of mineral additives on the hydration process [11]. The results of the study show that the addition of silicon oxide-rich mineral components to the cement composition increases their hydraulic activity while maintaining the strength of cement composites during long-term operation [12].

Moreover, according to the research conducted by Wang et al., additives in OPC (Ordinary Portland Cement) can significantly affect the cement hydration process. Experimental results showed a strength reduction of more than 30%, which was attributed to the retardation of the hydration process [[13], [14]]. These findings are crucial for studying the impact of porphyrite additives on cement hydration and its strength characteristics.

Studies indicate that the incorporation of natural silicate rocks, such as porphyrite, into construction materials can significantly enhance their physical, mechanical, and chemical properties. Porphyrite is a volcanic-origin rock, with silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) as its main components. Due to its chemical composition, porphyrite exhibits pozzolanic and hydraulic activity, making it suitable for use in combination with various binding materials [[15], [16], [17], [18], [19]].

The production of composite cement with the addition of porphyrite has been recognized in recent years as one of the key innovative directions in the construction materials industry. This method enhances the overall energy efficiency of the cement manufacturing process and reduces its environmental impact. In traditional cement production, clinker is used as the main component; however, its calcination requires high temperatures (approximately 1450°C). This process consumes a significant amount of thermal energy and releases a large volume of CO_2 into the atmosphere due to the thermal decomposition of carbonate raw materials [[20], [21], [22]].

The incorporation of natural additives, such as porphyrite, into the cement composition allows for a reduction in clinker content, which, in turn, decreases the overall energy consumption during production. Additionally, due to the natural composition and chemical properties of porphyrite, its pozzolanic and hydraulic activity contributes to improving the physical and mechanical properties of cement. For example, silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3) present in porphyrite actively participate in the hydration process, promoting the formation of additional binding phases, which positively affects the strength and durability of the material [23].

Reducing clinker content lowers emission levels, thereby contributing to the reduction of the carbon footprint in the construction materials industry. For this reason, cement production with porphyrite additives is not only economically beneficial but also highly relevant in terms of environmental sustainability.

Moreover, various studies show that the strength and durability of porphyrite-based types of cement can exceed that of traditional cement. Particularly under long-term operation, such cements demonstrate high resistance to moisture, sulfate ions, and other aggressive external factors. This expands the potential applications of porphyrite types of cement in road construction, marine infrastructure, and other structures exposed to harsh environments.

Silicon dioxide (SiO_2) present in porphyrite reacts with calcium hydroxide ($Ca(OH)_2$) when combined with cement or other hydraulic binders, forming additional calcium silicate hydrates (C-S-H) [[24], [25]]. This process enhances the density and strength of the material. As a result, the compressive and flexural strength of materials with porphyrite additives increases. Furthermore, aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3) in porphyrite improve the chemical stability of the material and its resistance to external influences.

In addition, due to its pozzolanic activity, porphyrite influences the hydration process of cement and other binding materials. During this process, the reactive ions of SiO_2 and Al_2O_3 present in porphyrite interact with the hydration products, strengthening the material's microstructure. For this reason, porphyrite additives are considered a promising component for the production of concrete and other high-strength construction materials.

Another important feature of porphyrite is its environmental efficiency. The production of traditional clinker-based binding materials requires significant energy consumption and is accompanied by carbon dioxide (CO_2) emissions into the atmosphere. The use of natural additives, such as porphyrite, helps reduce the carbon footprint of the production process. In this regard, in recent years, many researchers have been exploring the potential of porphyrite for the production of environmentally friendly binding materials.

This article presents a scientific analysis of the potential for producing composite Portland cement based on the clinker of Karakalpak Cement LLC and porphyrites from the Karatau deposit, as well as the changes in mineralogical composition, microstructure, and the increase in hydraulic activity as a result of mechanical activation of mineral additives.

The study aims to investigate the hydration kinetics, microstructure changes, and mechanical properties of composite cement based on porphyrite, as well as to assess its potential for industrial production.

In addition, this article provides a detailed examination of the possibilities of using porphyrites from the Karatau deposit in cement production, their impact on the hydration processes, and the physico-chemical properties of Portland cement.

Experimental part

As the research material, porphyrite from the "Karatau-1" section of the Karatau deposit was selected. The primary matrix for forming the compositions of composite Portland types of cement (CPC) was ordinary Portland cement clinker (Cl) from LLC "Karakalpak Cement." Gypsum stone (GS) from the Kogon deposit was used to regulate the setting time.

Standard methods corresponding to the following regulatory documents were used for conducting physico-chemical studies and physico-mechanical tests. The chemical analysis of Portland cement clinker from LLC "Karakalpak Cement," gypsum stone from the Kogon deposit, and porphyrite from the "Karatau-1" section of the Karatau deposit was carried out by GOST 5382-91 (“Cements and materials for cement production. Methods of chemical analysis”).

The hydraulic activity of porphyrite was determined according to O‘z DSt 336:2024 “Active mineral additives for cements. Technical requirements.” The results were evaluated according to the requirements of GOST 31108-2003 based on the Student's t-test criterion. The physico-mechanical properties of cement samples with porphyrite additives (PC) were studied according to GOST 310.4-81 “Types of cement. Methods for determining the strength limit in bending and compression.” The evaluation of the results was carried out according to the requirements of GOST 31108-2020 “Cements for general construction. Technical requirements.”

The physico-chemical properties of "green" cement composites were studied using the following analytical methods: X-ray phase analysis (X-ray diffractometer XRO–6100, Shimadzu), DTA – thermal analysis (Netzsch Simultaneous Analyzer STA 409 PG), IR spectroscopy (Fourier spectrometer “IRTracer-100,” SHIMADZU CORP), and electron microscopic analysis (scanning electron microscope JSM-6490LV with INCA Energy energy-dispersive microanalysis systems and HKL-Basic structural analysis).

Results and Discussion

The chemical and mineralogical composition of clinker during the cement production process directly affects its strength, hardening kinetics, and hydraulic activity. The composition of the portland cement clinker (PC) produced by "Karakalpak Cement" LLC meets the requirements of O‘z DSt 2801. This clinker contains the main oxides: CaO (58.93%), SiO_2 (18.03%), Al_2O_3 (6.22%), and Fe_2O_3 (3.94%), whose ratio determines the hydraulic activity of the clinker. A high sulfate content can affect the clinker hardening process; therefore, to enhance its hydraulic activity and stability, the use of mineral additives is advisable. The high content of alite (C_3S – 55.04%) and belite (C_2S – 17.81%) in the clinker ensures rapid hardening and positively influences the mechanical properties of the final product.

Porphyrite, being one of the natural silicate rocks, exhibits pozzolanic activity due to its high content of silica (SiO_2 – 51.42%) and aluminum oxide (Al_2O_3 – 18.51%). The mineralogical composition of porphyrite from the Karatau deposit allows it to be used as a pozzolanic additive in the production of Portland cement.

SiO_2 and Al_2O_3 contained in porphyrite react with $Ca(OH)_2$ during the hydration process, forming additional calcium silicate hydrate (C-S-H), which enhances the strength of concrete and other construction materials. Moreover, the presence of Fe_2O_3 (7.53%) and MgO (0.98%) in porphyrite ensures its chemical stability and increases the material's resistance to environmental impacts.

Gypsum stone is used in cement production as the primary setting regulator. When mixed with clinker, it prevents the excessive reaction of C_3A (tricalcium aluminate) with SO_3, thereby limiting the rapid setting of cement and providing the necessary time for its processing. In this study, the gypsum used contains 92.02% $CaSO_4 \cdot 2H_2O$, which indicates its high quality as an additive (Table 1).

Table 1 - Chemical composition of raw materials

Material name	Oxide content, mass %								
	k.m.y	SiO_2	$A1_2O_3$	Fe_2O_3	SaO	MgO	SO_3	Pr.	∑
Clinker PC	0.32	18.01	6.25	3.92	58.91	1.99	5.56	5.05	100.0
	Mineralogical composition of Clinker, mass %								
	C_3S-55.04; C_2S-17.81; C_3A-5.15; C_4AF-15.47; CS-1.65								
Porphyrite	5.71	51.43	18.52	7.52	5.27	3.9	0.92	6.82	100.0
Gypsum stone	20.31	2.79	0.48	сл.	30.99	сл.	42.81	2.62	100.0
	$CaSO_4.2N_2O$ = 42.80x2.15 = 92.02%								

The Karatau-1 deposit is located in the Karauzyak district of the Republic of Karakalpakstan, 80 km southeast of the Kegeyli settlement, with total reserves exceeding 63 million tons. The porphyritic rocks of this deposit consist of fine particles, have a light gray color, and may acquire a brownish tint due to the presence of iron oxides. Due to the high silicon dioxide content (SiO_2 – 51.42%), these rocks belong to the group of pyroxene porphyrites.

Research results confirm that the porphyrite composition includes quartz (SiO_2), feldspars ($KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$), micas (biotite and muscovite), as well as amphiboles and pyroxenes. These components provide porphyrite with high mechanical strength and chemical resistance. Infrared (IR) spectroscopy of the porphyrite sample revealed absorption peaks in the 400–1100 cm^{-1} range (Figure 1).

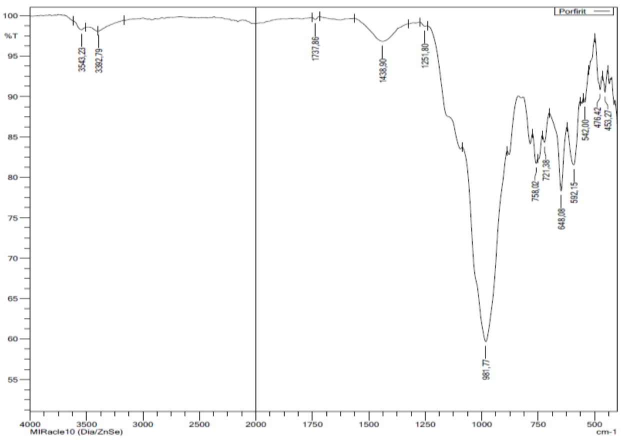


Figure 1 - Infrared (IR) spectroscopic analysis of porphyrite

The main recorded peaks are distributed as follows:

- 453.27 cm^{-1} and 470.42 cm^{-1} – Si-O-Al bonds typical for feldspars and amphiboles;
- 592.15 cm^{-1} and 648.08 cm^{-1} – stretching vibrations of pyroxenes and amphiboles;
- 721.38 cm^{-1} and 758.02 cm^{-1} – Si-O-Si bonds, indicating the presence of quartz and feldspars;
- 981.77 cm^{-1} – a pronounced absorption maximum associated with quartz stretching vibrations.

The physical and chemical properties of porphyrite allow its wide application in the construction industry. The high compressive strength and chemical resistance are associated with the following factors:

- High density and mechanical strength – due to the presence of hard minerals (quartz, feldspars, pyroxenes).
- Chemical resistance – the presence of silicates and oxide minerals makes porphyrite resistant to acidic and alkaline environments.
- Thermal stability – the content of silicon dioxide (SiO_2) and aluminosilicate minerals ensures the stability of the rock at high temperatures.

The results of the study show that porphyrite, due to its composition, can be used as a mineral additive in cement production. In particular, it has the potential to enhance the strength of cement and improve its hydraulic activity. Moreover, the use of porphyrite in road pavements and the production of durable construction materials is also considered feasible.

The mineralogical composition of porphyrite was determined based on the results of X-ray diffraction analysis (XRD). The most intense peaks on the diffractogram correspond to various minerals. A detailed analysis of the obtained data is provided below:

- Quartz (SiO_2) – d/n values (0.424; 0.333; 0.244; 0.228; 0.212; 0.182).
- Feldspars – d/n values (0.631; 0.495; 0.468; 0.400; 0.375; 0.365; 0.318; 0.291; 0.282; 0.182; 0.178).
- Calcite ($CaCO_3$) – d/n values (0.303; 0.249; 0.228; 0.209; 0.200; 0.188).

- Hydromicas (muscovite, biotite, etc.) – d/n values (0.495; 0.365; 0.352; 0.333; 0.303; 0.291; 0.282; 0.254).
- Chlorite minerals – d/n values (0.700; 0.631; 0.495; 0.468; 0.385; 0.375; 0.365; 0.291; 0.259; 0.244; 0.228; 0.212; 0.188; 0.182; 0.178; 0.156) (Figure 2).

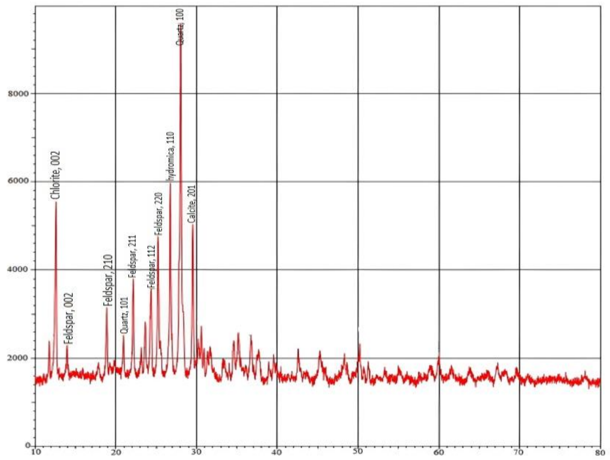


Figure 2 - X-ray diffraction (XRD) spectrum of porphyrite from the "Karatau-1" deposit

The presented image shows the XRD spectrum of porphyrite rock, containing various peaks. The most intense peaks on the diffractogram confirm the presence of quartz, feldspars, and hydromicas. Specifically, the peaks with d/n = 0.375 and 0.365 correspond to feldspars, indicating the predominance of silicate minerals in the composition of porphyrite. Additionally, the peaks with d/n = 0.424 and 0.333 indicate the dominant content of quartz.

The presence of hydromicas and chlorites in the composition of porphyrite affects its mechanical properties, allowing its use as an active mineral additive in cement compositions. Hydromicas and chlorites exhibit pozzolanic activity and contribute to the formation of calcium silicate hydrate (C-S-H), which provides additional strength during hydration.

To study the thermal properties of porphyrite, differential scanning calorimetry (DSC) analysis was conducted. According to the research results, a two-step water loss process is observed when heating porphyrite samples (Figure 3).

At the first stage (in the range of 25–140°C) at Tmax = 60°C, a pronounced endothermic effect was observed, associated with the release of water molecules adsorbed on the surface of porphyrite. The enthalpy of this reaction was -138.5 J/g, indicating a high content of free or weakly bound water in the porphyrite structure.

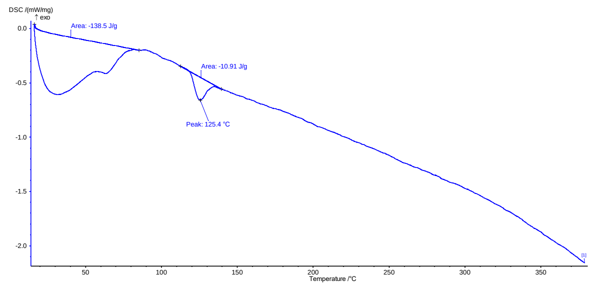


Figure 3 - Differential scanning calorimetry (DSC) analysis of porphyrite

In the second stage (Tmax = 125.4°C), the release of chemically bound water from the crystal lattice of the mineralogical composition of porphyrite occurred. This process is due to the thermal decomposition of hydrated minerals (e.g., hydromicas or chlorites), with the reaction enthalpy being -10.91 J/g. The obtained results are crucial for understanding the hydration properties of porphyrite in the cement production process. They serve as the basis for assessing the feasibility of using porphyrite as an active mineral additive in composite types of cement.

According to the study results, the hydraulic activity of porphyrite based on the Student's t-criterion was t = 24.47. This indicator significantly exceeds the threshold value of t = 2.07 established by the O‘z DSt 336:2024 standard. This proves that porphyrite possesses sufficient hydraulic activity and can be used as an active mineral additive in Portland cement.

Silicon dioxide (SiO_2) and other oxides present in porphyrite play a vital role in the hydraulic binding processes, contributing to the increased strength of cement. The conducted research has scientifically justified the potential of using porphyrite and sandstone as mineral additives in Portland cement production.

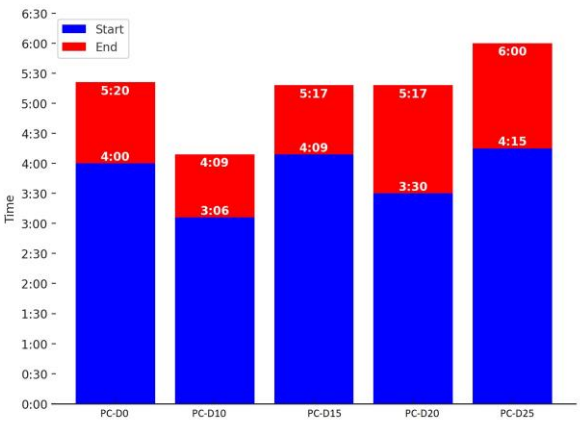
The production of composite cement based on porphyrite can not only improve product quality but also be economically efficient. The use of natural mineral additives reduces clinker consumption and helps decrease energy costs.

The addition of porphyrite to Portland cement clinker significantly affects the grinding process. According to the data presented in Table 2 and Figure 4, the research results show that as the amount of porphyrite increases, the fineness of the cement powder decreases. Sieve analysis through sieve №. 008 (4900 openings/cm²) revealed that the difference in fineness between pure Portland cement and types of cement with 10–25% porphyrite addition ranges from 0.5% to 2.0%.

Table 2 - The influence of porphyrite addition on the grindability of Portland cement clinker

№ p/p	Cement Designation	Component Ratio, wt. %		Grinding Time, min	Residue on Sieve № 008, wt. %
		Clinker + Gypsum stone	Porphyrite		
1	PC-D0	100	-	40	9.5
2	PC -D10	90	10	40	10
3	PC -D15	85	15	40	11
4	PC -D20	80	20	40	11.5
5	PC -D25	75	25	40	11.5

This process is explained by the fact that the physico-mechanical properties of porphyrite affect the grinding of clinker. Specifically, when milling the raw mix with the addition of porphyrite, the adhesion forces between particles and their density change, leading to a reduction in the number of fine fractions. This, in turn, influences the final particle size distribution of the cement and determines its rheological (flow) properties.



	PC-D0	PC-D10	PC-D15	PC-D20	PC-D25
End	5:20	4:09	5:17	5:17	6:00
Start	4:00	3:06	4:09	3:30	4:15

Figure 4 - The change in the setting time of portland cement produced by "Karakalpakcement" LLC depending on the porphyrite additive content (mass %): 1 - PC-D0 (0% porphyrite); 2 - PC-D10 (10% porphyrite); 3 - PC-D15 (15% porphyrite); 4 - PC-D20 (20% porphyrite); 5 - PC-D25 (25% porphyrite).

From the provided table and diagram, it is evident that increasing the porphyrite content reduces the cement setting time. Without additives, Portland cement (PC-D0) began its initial setting after 4 hours, while the final setting lasted 5 hours and 35 minutes. With the addition of 10% porphyrite (PC-D10), the initial setting time decreased to 3 hours and 15 minutes, while the final setting was completed within 4 hours and 15 minutes. As the porphyrite content increased, the initial setting time was further reduced, and with 25% porphyrite (PC-D25), it dropped to 3 hours and 5 minutes, with the final setting occurring in 4 hours and 10 minutes.

These results show that porphyrite reacts with clinker, accelerating the cement hydration process. This reduces the time required to achieve initial strength, making the cement more convenient for use in construction processes within shorter periods.

To determine the actual hydraulic activity of the cement, a technological batch was prepared, containing 80% clinker and 20% porphyrite, in accordance with the requirements of GOST 30744-2001. The resulting cement was tested following the methodology of GOST 310-91 using standard prismatic samples with dimensions of 4×4×16 cm (Table 3).

According to the table, increasing the porphyrite content significantly affects the compressive strength of the cement.

Cement with 100% clinker showed the highest strength:

- 2 days – 34.1 MPa
- 7 days – 36.0 MPa
- 28 days – 48.0 MPa

With the addition of 10% porphyrite, the strength slightly decreased:

- 2 days – 27.0 MPa
- 7 days – 31.0 MPa
- 28 days – 36.5 MPa

With 15–25% porphyrite content, the strength decreased even further. For cement with 25% porphyrite, the strength after 28 days was 31.8 MPa.

Table 3 - Physical and mechanical properties of types of cement with porphyrite additive

№	Mass percentage of component ratio		Compressive strength of 2×2×2 cm cube samples, MPa		
	Clinker	Porphyrite	2 days	7 days	28 days
1	100	-	34.1	36.0	48.0
2	90	10	27.0	31.0	36.5
3	85	15	25.1	29.0	35.0
4	80	20	20.5	28.8	34.5
5	75	25	20.0	28.0	31.8
Flexural/compressive strength of standard sanded Portland cement specimens measuring 4×4×16 cm, MPa					
			2 days	7 days	28 days
1	Clinker 100%	-	-	-	7.2/38.6
2	Clinker 80%	20%	4.9/24.2	5.8/32.5	6.9/34.6

Table 4 - Changes in the hydration activity of portland cement with porphyrite additives

№	**Cement type**	**Amount of chemically bound water (%) at the following time intervals:**			
		2 days	7 days	28 days	90 days
1	PC-D0	11.89	13.4	19.54	17.56
2	PC with Porphyrite additive	11.61	11.47	13.63	15.26

The analysis shows that the porphyrite additive affects the cement strength (Table 4). However, cement with 20% porphyrite meets the requirements of grade PC-D20 (32.5N). Such cement reached a strength of 32.5 MPa after 7 days, which complies with the requirements of GOST 30744-2001. Cement with 80% clinker and 20% porphyrite demonstrates optimal strength characteristics. Based on the results of 28-day tests, cement with 20% porphyrite achieved a cement strength subclass of 32.5N, confirming its suitability for construction use (Figure 5).

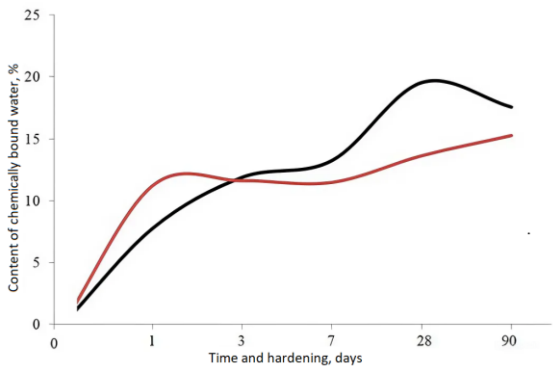


Figure 5 - The change in the content of chemically bound water during the hardening process of blended types of cement depending on the porphyrite content: №1 (————) PC-D0 (pure portland cement); №2 (————) PC-D20-PO (portland cement with 20% porphyrite addition).

These results validate the stability of the mechanical properties of types of cement with porphyrite additives and their potential application as building materials.

The hydration results of Portland cement with porphyrite additives indicate that porphyrite extracted from the "Koratov-1" site of the Koratov deposit modifies the hydration process of Portland cement. In such cement, water absorption decreased to 0.28–1.77% within 2–7 days, and by the 28th day, the amount of bound water became nearly identical (18.63% and 19.54%).

The introduction of porphyrite led to a 20% reduction in C_3S content, causing a slight slowdown in the hydration process. However, the resulting cement stone demonstrated high strength, meeting the strength class 32.5N requirements.

After three months of observation, the amount of bound water reached 15%, which is 2.3% lower compared to conventional cement. This indicates a gradual hydration process and the absence of rapid crystallohydrate formation, which contributes to enhanced durability and strength of the cement.

On the diffractograms of cement with the addition of porphyrite, prominent lines of calcium hydroxide and calcium carbonate were observed within the first day, with their intensity remaining almost unchanged for up to three days (Figure 6).

The study results demonstrate that the addition of porphyrite significantly affects the hydration process of Portland cement. The data on the change in the amount of chemically bound water correspond to the XRD results. Although, at the initial stage (within the first day), the amount of chemically bound water in cement with porphyrite is higher, at the 28-day and 90-day intervals, this indicator is lower compared to traditional Portland cement (PC-D0), indicating a slight deceleration of the hydration process.

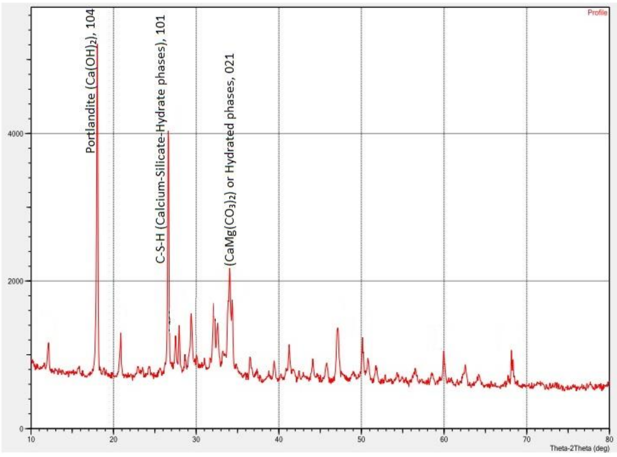


Figure 6 - X-ray Diffraction Pattern of Portland Cement with 20% Porphyrite Addition, Hydrated in Water for 28 Days

The diffractogram clearly shows distinct lines corresponding to calcium hydroxide ($Ca(OH)_2$) and calcium carbonate ($CaCO_3$), indicating the parallel progression of hydration and carbonation processes.

During hydration, the presence of hydrated calcium silicate phases (C-S-H) was also detected, which form as a result of the decomposition of C_3S (alite) and C_2S (belite). However, the addition of porphyrite slightly slows down this process, which may reduce the early strength development rate of the cement but does not affect its final strength.

Conclusions

In the course of the conducted research, the hydration processes of Portland cement with the addition of porphyrite, as well as its physico-chemical properties, were studied. The obtained results showed the following:

• Hydration process – the addition of porphyrite slightly slowed down the cement hydration rate; however, the final degree of hydration did not significantly affect the cement strength. This is mainly due to the reduction in C_3S content and the formation of calcium hydroxide ($Ca(OH)_2$) in the cement system.

• Chemically bound water content – an increase in the amount of bound water was observed during the first day, but at the 28- and 90-day intervals, this indicator was lower than that of traditional Portland cement (PC-D0), indicating a gradual hydration process.

• X-ray phase analysis (XRD) – distinct lines of calcium hydroxide and calcium carbonate were clearly recorded in the cement with porphyrite addition, with their intensity remaining unchanged during the first three days. This confirms the slower hydration of minerals in the cement system.

• Mechanical properties – the strength indicators of cement stone with porphyrite addition meet the requirements of strength subclass 32.5N cement, ensuring its stability.

These results confirm that the use of porphyrite as an additive can be an effective solution in cement production, offering an alternative raw material. Further, more detailed studies on the long-term stability of cement with porphyrite addition, using thermal analysis and other physico-chemical methods, are necessary.

Conflicts of interest. On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Цемент өнеркәсібіндегі көміртегі мөлшерін азайту үшін табиғи силикат жыныстарын пайдалану

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ТҮЙІНДЕМЕ

Портландцемент өндірісі көп энергияны тұтынады және CO_2-ның шығарындылары бар. Бұл экологиялық тұрақтылықты жақсарту үшін балама шикізат қажет болатынын көрсетеді. Зерттеу нәтижелері табиғи силикат жынысы порфириттің пуццоландық және гидравликалық белсенділігін көрсетті, бұл оны композиттік цемент өндірісінде перспективалы қоспаға айналдырады. Бұл зерттеуде порфиритпен модификацияланған портландцементтің физика-химиялық қасиеттері мен гидратация процестері рентгендік дифракция (XRD), дифференциалды термиялық талдау (DSC) және Фурье-трансформациялық инфрақызыл спектроскопия (FTIR) көмегімен талданды. Цемент үлгілерінің қысу күші мен қату уақыты МемСТ 30744-2001 және МемСТ 310-91 стандарттары бойынша тексерілді. Нәтижелер көрсеткендей, порфирит қосылғанда гидратация процесі аздап баяулайды, C_3S мөлшері азаяды, бұл кальций гидроксидінің ($Ca(OH)_2$) түзілуіне ықпал етеді. Құрамында 20% порфирит бар цемент 32,5N беріктік класының талаптарына сай болды және тұрақты механикалық қасиеттерді көрсетті. Суды сіңіру сынақтары кристаллогидрат кенеттен түзілмейтінін, гидратация процесі біртіндеп жүретінін растады. Бұл зерттеу порфирит цементтің беріктігіне, клинкерді тұтынуды азайтуға және энергияға сұранысты төмендетуге ықпал ететін тиімді минералды қоспа екенін дәлелдеді. Болашақ зерттеулерде озық термиялық талдау әдістерін қолдана отырып, порфирит негізіндегі цементтің ұзақ мерзімді тұрақтылығына назар аудару керек болады.

Түйін сөздер: Поцзоландық белсенділік, гидратация процесі, кальций гидроксиді ($Ca(OH)_2$), физика-химиялық қасиеттері, рентген сәулелерінің дифракциясы (XRD), дифференциалды термиялық талдау (DSC).

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Использование природных силикатных пород для снижения углеродного следа в цементной промышленности

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АННОТАЦИЯ

Производство портландцемента сопровождается высоким энергопотреблением и выбросами CO_2, что подчеркивает необходимость использования альтернативного сырья для повышения экологической устойчивости. Результаты исследований показывают, что порфирит, являющийся природной силикатной породой, обладает пуццоланической и гидравлической активностью, что делает его перспективной добавкой при производстве композитного цемента. В данном исследовании были проанализированы физико-химические свойства и процессы гидратации портландцемента, модифицированного порфиритом, с использованием рентгеновской дифракции (XRD), дифференциального термического анализа (DSC) и инфракрасной спектроскопии с преобразованием Фурье (FTIR). Прочность на сжатие и время схватывания цементных образцов определяли в соответствии со стандартами ГОСТ 30744-2001 и ГОСТ 310-91. Результаты показали, что добавление порфирита несколько замедляет процесс гидратации, снижая содержание C_3S, но способствует образованию гидроксида кальция ($Ca(OH)_2$). Цемент с 20% содержанием порфирита соответствовал требованиям прочностного класса 32.5N и демонстрировал стабильные механические свойства. Испытания на водопоглощение подтвердили постепенный процесс гидратации без резкого образования кристаллогидратов. Данное исследование подтверждает, что порфирит является эффективной минеральной добавкой, способствующей повышению долговечности цемента, снижению потребления клинкера и уменьшению энергозатрат. В дальнейшем рекомендуется изучить долгосрочную стабильность цемента с добавлением порфирита с применением передовых методов термического анализа.

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