

Представлені дослідження розкривають ефективний шлях утилізації продуктів водоочистки – їх використання у якості частини лужних цементів та бетонів на їх основі. Широке використання відходів очищення промислових стоків у складі будівельних матеріалів традиційно обмежене завдяки вмісту сполук важких металів у складі відходу. Матеріали, що створюються із використанням таких відходів, традиційно вважаються такими, що несуть небезпеку для здоров'я людини та навколишнього середовища. Використання саме лужних цементів як матриць для зв'язування вказаних відходів та супутніх продуктів дозволяє розв'язати проблему надійного зв'язування важких металів. Встановлено, що основними кристалічними фазами є кальцит, кварц, коецит, гематит та діопсид. Також визначено наявність гелеподібних новоутворень, які у подальшому здатні до рекристалізації у цеолітоподібні фази. Такий склад новоутворень забезпечує залучення іонів важких металів до хімічної структури отриманого матеріалу. Міцність при стиску розроблених лужноактивованих систем із використанням продуктів водоочистки (промислових стоків гальванічних процесів) сягає до 40 МПа у стандартних розчинах. Використання розроблених цементів у бетонах дозволяє сягнути міцності 45 МПа без зміни технологічного процесу виробництва бетону. Вилугування важких металів з матриці лужних цементів вивчали після витримування до 28 діб шляхом використання атомно-абсорбційної спектроскопії. В результаті дослідження було показано, що матриця лужного цементу характеризується високими іммобілізаційними властивостями по відношенню до сполук важких металів (рівень іммобілізації іонів важких металів до 99 %) та дозволяє використовувати продукти очистки промислових стоків у складі лужних цементів та бетонів на їх основі. Застосування такого підходу дозволить не тільки розв'язати питання утилізації небезпечних відходів водоочистки, вирішуючи екологічні проблеми, але й також дозволить отримувати будівельні матеріали загальнобудівельного призначення, що характеризуються високими експлуатаційними властивостями

Ключові слова: промислові стоки, технологія феритизації, лужні цементи, феритні осади, вилугування іонів важких металів

1. Introduction

One of the urgent problems of our time is the treatment and disposal of liquid waste from industrial production. The extent of the environmental pollution from heavy metals (HM) that are a threat to living organisms has considerably increased recently. Therefore, improving the environmental safety by introducing energy-efficient water treatment equipment, development of low-waste technologies with closed systems of resource circulation is a priority direction in the development of modern industry, and in particular, electroplating equipment. Recently, in order to comprehensively treat the wastewater of electroplating production, those operations that relate to the application of certain metallic coatings are separated into a dedicated line. In this case, it is possible to create local systems of water purification [1].

Electrolytic production mostly employs conventional reagent methods, which previously ensured the cleaning of

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DEVELOPMENT OF A TECHNOLOGY FOR UTILIZING THE ELECTROPLATING WASTES BY APPLYING A FERRITIZATION METHOD TO THE ALKALINE-ACTIVATED MATERIALS

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wastewater in accordance with accepted standards of its discharge into the municipal sewer system [2]. However, given that these requirements become stricter, the water purified by a reagent method is not suitable for reuse at an enterprise or dumping in city sewers. As a result, the insufficiently purified electroplating wastes bring significant amounts of HM, specifically highly toxic compounds of nickel, to water facilities. Their share in the wastewater from electroplating production reaches 20 % of the total content of HM [3]. Thus, it is a relevant task to improve approaches to recycling such a wastewater, in particular, the application of the concept aimed at the efficient cleaning of water with further disposal of the generated water treatment products.

One of the most effective and promising methods for disposing of water treatment products is their use as ingredients for the manufacture of building materials as this approach makes it possible to recycle and dispose of large amounts of waste. The volume of construction materials market theoretically makes it possible to easily involve in

the product creation process all the waste generated from water treatment.

The relevance of research in the proposed field is predetermined by the fact that there is an urgent need to dispose of water treatment waste that accumulate at enterprises. Such waste cannot be dumped in sewage systems because of its danger to the environment. Storing such waste at enterprises also poses elevated environmental risks and worsens the economic performance of production due to the need to ensure the safe storage and handling of such waste. Exploiting such waste to create building materials will not only reduce environmental risks and economic burden on enterprises, but would also make it possible to gain additional economic effect from selling construction products, as well as bring down the general level of production waste almost to zero. However, at present, conventional cement systems do not make it possible to efficiently bind the heavy metals ions at the chemical level and do not provide for their immobilization. It is necessary to use other types of binders that are able to provide reliable immobilization of heavy metals.

2. Literature review and problem statement

In recent years, special attention has been paid to the development of processes for treating industrial wastewater with a minimum volume of sludge at high degree of removal of heavy metals ions. One of such techniques is ferritic [3], which is a modification of the reagent method of purification. This method implied that the wastewater that contains heavy metals ions is added with a solution of FeSO_4 . After adding alkali followed by bubbling with oxygen or air at a temperature of 50–80 °C ferrite forms in the mortar, which is easily separated at magnetic filters. The primary reagent for ferritic wastewater treatment is sulfate hydrate ferrous iron $\text{FeSO}_4 \times 7\text{H}_2\text{O}$, which is a waste from the production of titanium dioxide or etched steel [4].

It should be noted that the process of ferritization is rather energy-intensive, as it typically occurs at a temperature above 70 °C. An alternative to the high-temperature activation of ferritization process could be wastewater treatment with electromagnetic pulsed discharges [4]. Application of electromagnetic pulsed discharges makes it possible to significantly intensify the treatment process, reduce the duration of a technological cycle [5], bring down energy consumption, abandon the construction of bulky water treatment facilities.

However, the process of wastewater treatment when using this method, in addition to the formed ferritic sediments, leads to the formation of a liquid waste with an elevated content of soluble salts. The obtained solid and liquid wastes require further environmentally-friendly recycling, for example, in the production of materials for various purposes, and, when it is impossible to manufacture marketable products, should be buried in open dumps [6]. Such storage methods are a significant danger to the environment and require significant financial costs.

One of the promising ways for comprehensive disposal of industrial wastewater treatment products is to use them as components for water mixing and for the filler of alkaline cements [7]. These materials have unique performance properties, and include in their composition to 95 % of waste and related industrial products (fuel ash [8], blast furnace granulated slags [9], etc. [10]). In this case, such materials are not

inferior to their analogs, based on conventional cements, in terms of their properties.

Previous studies have shown that alkaline cements are resistant to the effect of aggressive environment [11], they excellently interact with solutions of sulphates and chlorides [12], and possess a wide range of unique operational properties [13]. They make it possible to reliably fix in their structure the elements of radioactive and HM, not only at the physical [14] but also at the chemical level [15]. However, those studies did not consider a possibility for the disposal of waste from the ferritic purification of galvanic discharge, which differs greatly in chemical composition from the studied systems.

The use of water treatment products (electroplating sludge) for the production of building materials in the conventional cement systems is limited by the high content of heavy metals ions in their composition (Fe, Cu, Zn, Ni, etc. [16]), at the same time, a possibility to dispose of them is one of the ways to apply alkaline-activated cements and composite materials based on them [17]. The alkaline-activated cements and concretes are able to safely exploit iron-containing waste with a high content of heavy metals [18]; they demonstrate high operational characteristics [19]. They also have a range of specialized properties [20].

Previous studies have shown that the main products from hydration of alkaline-activated cements are the C–S–H gel [21], zeolites [22] and hydrogranates [23]. Such a composition of new structures makes it possible to reliably fix the elements of heavy metals in the structure of a material. The process of forming hydrated phases depends on the ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$, which affects the durability [16] and formation of zeolite-like products, which are the most reliable structures to retain heavy metals at the chemical level [24].

Paper [8] studied the processes of minerals formation at different temperatures in the range of 20–80 °C and established that the obtained neoformations were represented by zeolite Na–A, sodium or potassium heulandite and phillipsite. However, obtaining the zeolite-like neoformations in alkaline-activated cements is possible not only in the sodium systems – geocements [25], but also in calcium-containing systems [26], which, instead, need much more time for crystallization. The main crystalline neoformations in such systems at the initial stage are the low-base calcium hydrosilicates [27].

Thus, an analysis of the scientific literature has revealed the possibility for a reliable and safe disposal of hazardous waste in the matrix of alkaline-activated cements. This allows us to assume that the use of such cements could also prove effective for the immobilization of elements of heavy metals from the waste of water treatment using the method of ferritization. The application of such cements should make it possible to bind harmful compounds in the structure of cement neoformations and thus fix them not only at the physical but also at the chemical level. In addition, that would make it possible to potentially obtain materials with high operational characteristics that are safe for humans and the environment.

3. The aim and objectives of the study

The aim of this study is to examine the properties of alkaline cements that include products from water treatment of electroplating wastes by ferritization.

To accomplish the aim, the following tasks have been set:

- to explore the mineralogical composition of alkaline-activated cements that include water treatment products;
- to study the physical-mechanical and physical operational properties of the designed materials;
- to explore the properties of the matrix of alkaline-activated cements relative to the heavy metals from the composition of water treatment products.

4. Materials and methods of research

4.1. Basic components of alkaline-activated cements

The basic components of alkaline cement that were used included granulated blast-furnace slag with a specific surface of 450 m²/kg (by Blaine) and a content of the glass phase of about 80 % and low calcium (Class F, classification ASTM C 618) and fly ash (FA) with a specific surface of 800 m²/kg. Chemical composition of the examined materials is given in Table 1.

Chemical composition of raw materials

Material	Content of basic oxides, % by weight												Weight loss, %
	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	
Slag	37.9	0.35	6.85	–	–	0.106	5.21	44.6	–	–	–	–	–
Ash	50.94	0.94	24.56	13.25	–	0.03	1.98	2.86	0.69	2.69	0.02	–	1.36

The basic alkaline components used was calcined soda (Na₂CO₃). To adjust the rheological properties of the material, we used sodium lignosulfonate in the amount of 0.5 % by weight in a powdered state.

4.2. Water treatment products

The process of ferritization was performed at two laboratory installations [3]. The first applied the thermal method of mortar activation ($T=70$ °C); its main working elements are a thermostat, a thermoelectric heater (TEH), the rheostat RPSH-5, and a compressor with an air distribution system. The second installation used electromagnetic pulse activation ($T=20$ °C) with an amplitude of magnetic induction in the working area of 0.23–0.43 Tl, a range of generating frequencies of up to 0.9 kHz and a power of 30 W. Each signal was composed of packets of impulses (16 pulses per packet). Interval between packets was 1,300 ms. Period between pulses was 20 ms. Pulse duration was 35 ms. The main elements of this setup are a reactor, an electronic block body, pulsers, a compressor with an air distribution system. The process of ferritization without additional activation was performed at the first installation without enabling the heating elements (TEH) at $T=20$ °C.

The sediment obtained after ferritization was compacted for 2 minutes in the centrifuge OPn-8 (UHL 4.2) with the rotor RU-180 L (Dastam M, Russia) at a separation factor of 3,600. Structural analysis of the derived sediments was carried out by a powder x-ray diffraction under a step mode with Cu-K α radiation at the diffractometer XRD-6000 (Shimadzu, Japan).

Phase composition of the dried powders of alkaline cements was determined at the automated diffractometer PW-1004 (Philips, the Netherlands). Differential-thermal (DTA) and thermogravimetric (TG) analyses were carried

out at the device Derivatograph-Q (MOM, Hungary) at a sample heating rate of 10 °C/min to a temperature of 1,000 °C. Raster electron microscopy was performed at the device REMMA-102 (LLC “SELM”, Ukraine).

The products from industrial wastewater treatment are represented in the form of filtrates (electrolyte) and ferritic residues. On the one hand, the electrolyte is a liquid with a low content of ions of heavy metals, which is in compliance with regulations on water, but, on the other hand, their subsequent discharge to rivers or other bodies of water is problematic due to the high level of pH (pH=10.21). At the same time, the alkaline environment of the electrolyte contributes to the structure formation of alkali cements because it was established [28] that mixing such cements with solutions of sulphates or chlorides improves operational properties [29]. Results from the chemical analysis of electrolytes are given in Table 2.

Ferritic sediments that were received via different methods of ferritization process activation (thermal activation at a temperature above 70 °C, electromagnetic activation) demonstrate a high degree of crystallinity. An analysis of phase composition revealed the presence of iron oxides: Fe₃O₄ and γ -Fe₂O₃, as well as nickel peroxide Fe₂NiO₄. The determined phases had the ferro-magnetic properties and a spinel-like crystal lattice. Quantitative phase composition is shown in Fig. 1.

Table 1

Table 2

Chemical composition of electrolytes

No.	Property	Value	Method
1	Sulphates (SO ₄ ²⁻), mg/dm ³	25,616	GOST 4389-72
2	Chlorides (Cl ⁻), mg/dm ³	1,186	GOST 4245-72
3	Heavy metals ions, mg/dm ³ :		GOST 32221-2013
	– Fe ^{total}	0.1	
	– Ni ²⁺	0.42	
4	pH	10.21	pH-meter

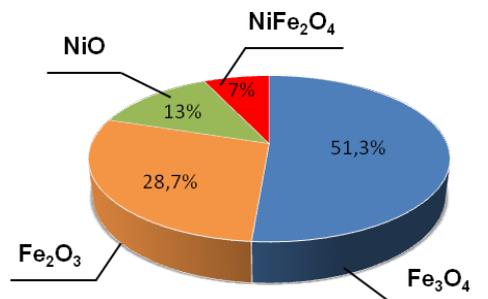


Fig. 1. Phase composition of ferritic sediments

Fig. 1 shows that according to their chemical composition the ferritic sediments contain compounds of heavy metals (nickel, iron) in large quantities and therefore require the use of effective technologies for their processing and binding to safe compounds and materials, in particular using alkaline cements.

5. Results of research into operational properties of alkaline-activated materials using water treatment waste

5. 1. Examination of mineralogical composition of neo-formations in the alkaline cements that contain products from water treatment by the ferritization method

To investigate a possibility of safe immobilization of heavy metals, the waste from industrial water treatment were used as a component of hybrid alkaline cements. Ferritic sediments were introduced in the amount of 2.5–7.5 % by weight of cement and mixed with the electrolyte. Compositions of the examined cement pastes and their mechanical properties are given in Table 3.

Table 3

Composition and properties of alkaline cements that include wastewater treatment products

No.	Cement composition, %					Paste of normal consistency, %	Compressive strength, MPa, 28 days
	Slag	Ash	Soda	Water (W)/ Electrolyte (E)	Ferritic sediments		
Basic							
1	66.7	28.6	4.7	W	–	26	60.2
2	66.7	28.6	4.7	E	–	25	40.5
Ferritization at 20 °C							
3	65.0	27.8	4.7	E	2.5	27	56.2
4	63.3	27.0	4.7	E	5.0	28	51.2
5	61.5	26.3	4.7	E	7.5	26	58.7
Ferritization with thermal activation							
6	65.0	27.8	4.7	E	2.5	26	54.5
7	63.3	27.0	4.7	E	5.0	26	62.0
8	61.5	26.3	4.7	E	7.5	26	50.2
Ferritization with electromagnetic activation							
9	65.0	27.8	4.7	E	2.5	26	55.0
10	63.3	27.0	4.7	E	5.0	26	62.2
11	61.5	26.3	4.7	E	7.5	26	52.7

Based on the obtained results, it can be noted that the replacement of water with electrolyte and the introduction of sediments do not affect the consistency of cement pastes and changes their strength indicators in a limited range.

We studied the phase composition of neo-formations for systems that included ferritic sediments of up to 7.5 % (formulations 1, 2 – basic, 5, 8, 11 – with ferritic sediments) (Fig. 2). Composition of the neo-formations is given in Table 4.

Based on the results of a physical-chemical study, it was established that the basic products of hydration are calcite (3.029; 2.088; 1.869) CaCO₃ [30] (Fig. 2, a), whose presence is confirmed by the effect at 805–860 °C at a DTA curve (Fig. 2, b). However, mixing the cement with electrolyte increases the content of calcite, slowing the crystallization process of vaterite. Thus, the content of CaCO₃ increases from 45 to 61 % relative to the content of all mineral phases. The introduction of ferritic sediments also leads to an increase in the content of calcite, to 69 %, by reducing the intensity of CaSiO₃ formation. The content of quartz and coesite, which are easily identified owing to their crystal structure, is within 2–8 % depending on the type of sediment. Thus, for the case of thermal or electromagnetic activation, there is an increase in the content of quartz and a decrease in the content of coesite. The Ca-Mg neo-formations, represented by diopside (CaMgSi₂O₆), which is confirmed by the effects at a DTA curve at 700–800 °C, typically have gel-like formations at the grain surface. Part of the ferritic sediments is identified as hematite (Fe₂O₃) and is less than 4 % of the mineral phases.

The fracture surface of artificial stone represents evenly distributed gel-like neo-formations and calcite (Fig. 3). These gel-like (submicrocrystalline) neo-formations are the phases that are capable of subsequent recrystallization into zeolite-like neo-formations; the ions of heavy metals are incorporated into the composition of such neo-formations at the chemical level.

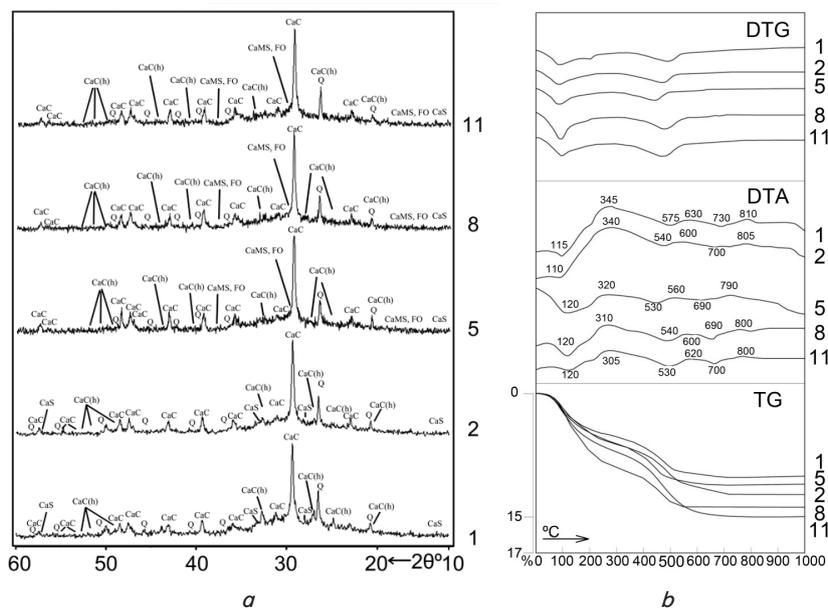
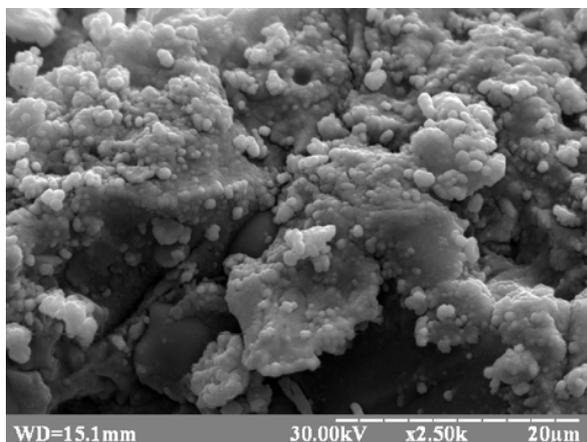


Fig. 2. Results from a physical-chemical study into alkaline-activated cements that include water treatment products: a – X-ray phase analysis, b – differential thermal analysis. Note: the identified phases: CaC, CaC(h) – calcite (CaCO₃), Q – quartz (SiO₂), CaMS – diopside (CaMgSi₂O₆), FO – hematite (Fe₂O₃), CaS – calcium silicate (CaSiO₃)

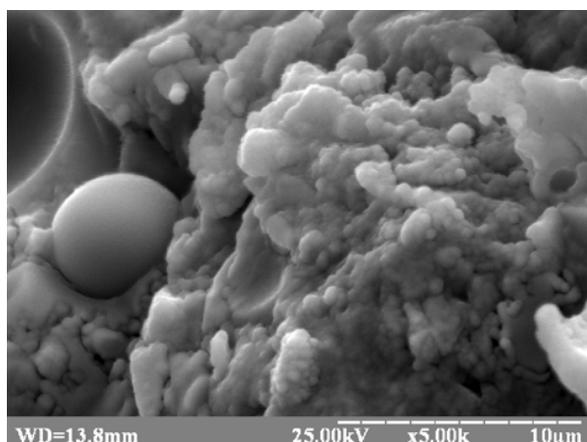
Table 4

Composition of cement stone neo-formations

Mineral	Composition, %				
	No. 1	No. 2	No. 5	No. 8	No. 11
CaCO ₃ calcite	45.39	61.03	62.24	69.82	68.01
SiO ₂ quartz	6.94	7.88	5.69	8.59	8.67
CaCO ₃ vaterite	22.66	10.65	3.07	2.67	1.63
CaSiO ₃ calcium silicate	6.44	4.57	2.80	2.64	2.11
SiO ₂ coesite	6.05	4.21	5.50	2.54	3.23
CaMgSi ₂ O ₆ diopside	8.90	6.44	8.55	7.36	8.27
CaCO ₃ argonite	3.61	5.23	8.43	4.61	6.42



a



b

Fig. 3. The fracture surface of alkali cement that includes using ferritic sediments as a component: a – magnification ×2,500; b – magnification ×5,000

The established composition of neo-formations potentially makes it possible to obtain high immobilizing properties and operational indicators of materials.

5.2. Studying the operational characteristics of examined cements and concretes

We studied the strength characteristics of alkaline-activated cements that include the products of water treatment in standard cement-sand mortars using an equal-water-cement ratio W/C, namely 0.4. The examined compositions are given in Table 5.

Table 5

Composition of alkaline cement that includes waste from water treatment

No.	Composition, (%)					W/C	Compressive strength, MPa, in days		
	Slag	Ash	Soda	Water/Electrolyte	Sediments		3	7	28
M 2	66.7	28.6	4.7	E	–	0.4	11.25	16.31	35.31
M 3	65.0	27.8	4.7	E	2.5	0.4	10.62	16.93	36.31
M 4	63.3	27.0	4.7	E	5.0	0.4	10.0	16.43	35.31
M 5	61.5	26.3	4.7	E	7.5	0.4	10.0	16.18	36.37
M 6	95.3	–	4.7	W	–	0.4	18.12	25.62	44.06
M 7	95.3	–	4.7	E	–	0.4	17.50	18.37	34.06
M 8	92.8	–	4.7	E	2.5	0.4	15.62	21.68	41.25
M 9	90.3	–	4.7	E	5.0	0.4	13.75	19.5	39.31
M 10	87.8	–	4.7	E	7.5	0.4	13.12	22.56	43.18

Strength at compression of mortars depends on the content of ferritic sediments in cement. Thus, for the case when the content of ferritic sediments is 7.5 % by weight the strength amounts to 43 MPa at the age of 28 days. This can be explained by denser and more bound structure of the stone as a result of increasing the content of calcite. The compositions of alkaline-activated cements that include fly ash are characterized by somewhat lower strength indicators (35–38 MPa) due to the slow accumulation of strength, traditional for ash-containing cements.

The examined cements were tested for the production of concrete mixtures (Table 6).

Table 6

Composition of alkali concretes that include the cement containing ferritic sediments

No.	Alkaline cement (kg/m ³)				Sand, kg	Gravel (5–20), kg	Water (W)/Electrolyte (E), l	Slump test, cm	Compressive strength, MPa, days		
	Slag	Ash	LST	Soda					3	7	28
1	2	3	4	5	6	7	8	10	11	12	13
C1	400	–	2	20	850	1130	W185	140	18.29	28.8	39.1
C2	280	120	2	20	850	1130	W185	185	11.01	30.6	45.7
C3	400	–	2	20	850	1130	E185	100	20.0	20.8	43.0
C4	280	120	2	20	850	1130	E185	165	13.6	27.2	41.0

The examined concretes show high intensity in the kinetics of strength accumulation and reach 45 MPa at the age of 28 days and, compared with the basic composition, prove that using the water treatment products does not affect the strength of concrete, even for the case when significant quantities of electrolyte are applied.

We studied the frost resistance of concretes by an express-method using a 5% NaCl solution at a freezing temperature of -45 ± 5 °C. Results from examining frost resistance are given in Table 7.

Carbonization of concretes in the age of 1 year was 6–8 mm; at the same time, the use of ash-containing cement led to a decrease in carbonation rate to 2–4 mm (Fig. 4).



Fig. 4. Carbonization of alkaline concretes that included water treatment waste

Such indicators of carbonization correspond to the indicators of carbonization for the alkaline-activated materials without adding water treatment waste, which indicates that the introduction of such products do not degrade the performance of the material.

Results from examining frost resistance

No.	Weight prior to testing, g	Weight after testing, g	ΔW , %	Strength after testing, MPa	Strength of control samples, MPa	Loss of strength, %	Number of cycles	Frost resistance in line with DSTU B V.2.7-47-96
C1	2,412	2,409	0.12	39.9	39.1	-2.00	4	F150
C2	2,417	2,412	0.2	46.4	45.7	-1.50	4	
C3	2,441	2,356	3.48	36.7	43.0	14.65	4	
C4	2,429	2,400	1.19	34.7	41.0	15.36	4	

5.3. Studying the immobilizing capacity of the matrix of alkaline-activated materials relative to the heavy metal ions

The reliability of immobilization of water treatment waste can be confirmed by examining the leaching of heavy metals from the body of the cement and concrete. The study was carried out by a statistical method on samples-cylinders of height 5.0 cm and a diameter of 2.8 cm. The ratio of volume of the dispersed medium to the disperse phase volume was 10:1. We evaluated results by determining the content of Fe and Ni ions in the environment of leaching using a method of atomic adsorption spectrometry at the age of 7, 14, and 28 days. The results obtained are shown in Fig. 5.

According to the obtained results, one can argue that the primary intensity in the leaching of heavy metals occurs on day 7, after which the process stabilizes. The total concen-

tration of heavy metals is negligible, 0.32 mg/dm^3 for Fe and 0.28 mg/dm^3 for Ni.

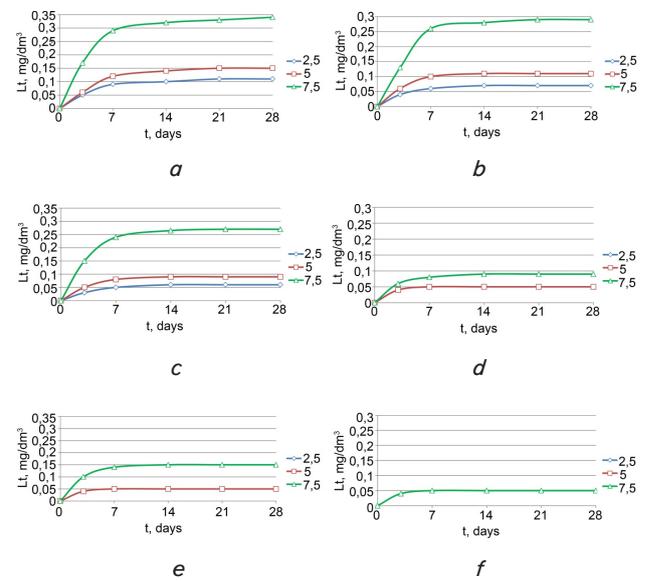


Fig. 5. The results of leaching Fe (a, c, e) and Ni (b, d, f) from the stone of alkaline cement that included water treatment products depending on the activation method at treatment: a, b – without activation, c, d – with thermal activation, e, f – with electromagnetic activation. Content of ferritic sediments in the composition: \blacklozenge – 2.5 % by weight; \blacksquare – 5.0 % by weight; \blacktriangle – 7.5 % by weight.

6. Discussion of results of devising a technology for the utilization of industrial wastewater in alkaline cements

Table 7

Based on the results of our work, taking into consideration the results reported earlier [3], we have devised a comprehensive approach to the utilization of industrial wastewater in the matrix of alkaline cements. We obtained cements that include the industrial wastewater treatment products, which, in terms of their strength indicators (strength at compression of up to 40 MPa), are not inferior to conventional analogs for general construction purposes. The concretes based on such cements are also characterized by high operational performance (strength at compression to 45 MPa).

The best immobilizing properties are demonstrated by the compositions that include ferritic residues obtained using the method of electromagnetic activation. This can be explained by the reorientation of iron-containing particles in space using electromagnetic pulses, which predetermines their increased activity. Our study has shown that the use of alkaline cements ensures high immobilization indicators for heavy metals elements in the structure of cement and concrete (the level of immobilization of ions of heavy metals is up to 99 %). It has been shown that the elements of heavy metals are bound at the chemical level, entering the structure of the neo-formations of the obtained materials, thereby providing their reliable fixation. Heavy metal elements are included into the structure of submicrocrystalline

neo-formations of alkaline cements, as evidenced by very low indicators for leaching these metals from the matrix. Identification of such neo-formations via conventional methods of physical-chemical analysis is not possible, since their dimensionality is less than that permissible for such methods. Such gel-like submicrocrystalline neo-formations are the basis for subsequent recrystallization into zeolite neo-formations.

Thus, it was proposed to use alkaline cements as matrices for the utilization of water treatment waste. It is shown that the use of such cements could help obtain materials for general construction purposes that are environmentally safe and are not inferior to conventional analogs in terms of performance indicators. Application of the proposed approach to using products from industrial wastewater treatment as a component of eco-friendly building materials would make it possible to receive an almost waste-free technology for the disposal of industrial waste from electroplating production.

The further research can address the possibilities of increasing the content of water treatment products in the composition of alkaline cements and concretes and establishing the influence of different water treatment technologies on the performance of concretes based on them.

6. Conclusions

1. We have investigated the mineralogical composition of alkaline-activated cements that include water treatment waste. It is shown that the main crystalline phases are calcite, quartz, coesite, hematite, and diopside. We have also defined the presence of gel-like neo-formations, which are later capable of recrystallization into the zeolite-like phases. Such a composition of neo-formations ensures the involvement of ions of heavy metals into the chemical structure of the resulting material.

2. Strength at compression of the examined mortars is 43 MPa at the age of 28 days, and for concrete – up to 45 MPa, which matches indicators for conventional analogs. The frost resistance of concrete is up to F150 and depends on the type of product from water treatment, which makes it possible to use such materials in construction.

3. We have proven high immobilizing properties of the matrix of alkaline-activated cements relative to heavy metals from the composition of water treatment products (the level of immobilization is up to 99 % by weight). This allows us to argue about the safety of using the designed materials from an environmental point of view.

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