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 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

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

O. Kovalchuk
PhD, Senior Researcher
Scientific-Research Institute for Binders and Materials named after V. D. Glukhovsky**
E-mail: kovalchuk.oyu@gmail.com

G. Kochetov
Doctor of Technical Sciences, Professor*
E-mail: gkochetov@gmail.com

D. Samchenko
PhD, Junior Researcher
Scientific Research Part**
E-mail: sama30071988@gmail.com

A. Kolodko
Postgraduate student*
E-mail: antoon11@ukr.net

*Department of Chemistry**
**Kyiv National University of Construction and Architecture

Povitroflotskyi ave., 31, Kyiv, Ukraine, 03037

DOI: 10.15587/1729-4061.2019.160959
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 FeSO₄. 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 FeSO₄·7H₂O, 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 hydrogarnets [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 SiO₂/Al₂O₃, 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 neo-formations 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-chemical 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 m$^2$/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 m$^2$/kg. Chemical composition of the examined materials is given in Table 1.

| Material | 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$_3$ | Weight loss, % |
|----------|--------|--------|------------|-----------|-----|-----|-----|-----|--------|-------|-----------|-------|--------------|
| Slag     | 37.9   | 0.35   | 6.85       | 0.00      | –   | –   | 0.00| 0.00| 0.00   | 0.00  | –          | 0.00  | –           |
| Ash      | 50.94  | 0.94   | 24.56      | 13.25     | 0.03| 1.98| 2.86| 0.69| 2.69   | 0.02  | 1.36       | 1.36  | 8.79        |

The basic alkaline components used were calcined soda (Na$_2$CO$_3$). 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 thermodlectric 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 and 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 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 "SEMLI", 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: Fe$_2$O$_3$ and γ-Fe$_2$O$_3$, as well as nickel peroxide Fe$_3$Ni$_2$O$_6$. The determined phases had the ferro-magnetic properties and a spinel-like crystal lattice. Quantitative phase composition is shown in Fig. 1.

Table 2

| 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$^3$: - Fe$_{total}$ | 0.1     | GOST 32221-2013  |
|     |                          |         |                   |
|     |                          |         | Ni$^{2+}$         |
|   4 | pH                      | 10.21   | pH-meter          |

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

| No. | Cement composition, % | Paste of normal consistency, % | Compressive strength, MPa, 28 days |
|-----|-----------------------|-------------------------------|-----------------------------------|
|     | Slag   | Ash   | Soda | Water (W)/Electrolyte (E) | Ferritic sediments |     |
| 1   | 66.7   | 28.6  | 4.7  | W                          | –                  | 26  | 60.5 |
| 2   | 66.7   | 28.6  | 4.7  | E                          | –                  | 25  | 40.5 |
| 3   | 63.3   | 27.0  | 4.7  | E                          | 2.5                | 27  | 56.2 |
| 4   | 61.5   | 26.3  | 4.7  | E                          | 7.5                | 26  | 58.7 |
| 5   | 65.0   | 27.8  | 4.7  | E                          | 2.5                | 26  | 54.5 |
| 6   | 63.3   | 27.0  | 4.7  | E                          | 5.0                | 26  | 62.0 |
| 7   | 61.5   | 26.3  | 4.7  | E                          | 7.5                | 26  | 50.2 |
| 8   | 65.0   | 27.8  | 4.7  | E                          | 2.5                | 26  | 55.0 |
| 9   | 63.3   | 27.0  | 4.7  | E                          | 5.0                | 26  | 62.2 |
| 10  | 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 (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)](image-url)
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   |

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. | Slag | Ash | Soda | Water/Electrolyte | W/C | Compressive strength, MPa, days |
|-----|------|-----|------|------------------|-----|-------------------------------|
|     | 66.7 | 28.6| 4.7  | W                | 0.4 | 13.12 20.62 38.81            |
| 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                | 0.4 | 10.62 16.93 36.31            |
| M 4 | 63.3 | 27.0| 4.7  | E                | 0.4 | 10.0 16.43 35.31             |
| M 5 | 61.5 | 26.3| 4.7  | E                | 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                | 0.4 | 15.62 21.68 41.25            |
| M 9 | 90.3 | –   | 4.7  | E                | 0.4 | 13.75 19.5 39.31             |
| M 10| 87.8 | –   | 4.7  | E                | 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 alkaline concretes that include the cement containing ferritic sediments

| No. | Slag | Ash | LST | Soda (5–20), kg | Water (W)/ Electrolyte (E), l | Slump test, cm | Compressive strength, MPa, days |
|-----|------|-----|-----|----------------|--------------------------|---------------|-------------------------------|
|     | 2    | 3   | 4   | 5             | 6                        | 7             | 10                           |
| C1  | 400  | –   | 2   | 20            | 850                      | 1130          | W185 140                     |
| C2  | 280  | 120 | 2   | 20            | 850                      | 1130          | W185 185                     |
| C3  | 400  | –   | 2   | 20            | 850                      | 1130          | E185 100                     |
| C4  | 280  | 120 | 2   | 20            | 850                      | 1130          | E185 165                     |

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).
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).

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.

![Fig. 4. Carbonization of alkaline concretes that included water treatment waste](image)

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 concentration of heavy metals is negligible, 0.32 mg/dm³ for Fe and 0.28 mg/dm³ 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: – 2.5 % by weight; – 5.0 % by weight; – 7.5 % by weight.](image)

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

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 ferrite 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 submicrocrystallic
neof-ormations 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 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.

### References

1. Enhanced phosphate removal from wastewater by using in situ generated fresh trivalent Fe composition through the interaction of Fe(II) on CaCO3 // Li Y., He X., Hu H., Zhang T., Qu J., Zhang Q. // Journal of Environmental Management. 2018. Vol. 221. P. 38–44. doi: https://doi.org/10.1016/j.jenvman.2018.05.018

2. Nakaz Derzhavnoho komitetu budivnyctvya, arkhitektury ta zhyttiovoi polityky Ukrainy vid 19 liutoho 2002 roku No 37. Pravyyla pryimannia stichnykh vod pidpryiemstv u komunalni ta vidomchi systemy kanalizatsii naselenykh punktiv Ukrainy.

3. Research of the treatment of depleted nickel plating electrolytes by the ferritization method // Kochetov G., Prikhna T., Kovalchuk O., Samchenko D. // Eastern-European Journal of Enterprise Technologies. 2018. Vol. 3, Issue 6 (93). P. 52–60. doi: https://doi.org/10.15387/1729-4061.2018.133797

4. Solidification of borate ion-exchange resins by alkalai-activated slag cements // Rakhimova N. R., Rakhimov R. Z., Lutskin Y. S., Morozov V. P., Osin Y. N. // Revista Romana de Material. / Romanian Journal of Materials. 2018. Vol. 48, Issue 2. P. 177–184.

5. Structure and properties of nickel ferrites produced by glow discharge in the Fe(II) on CaCO3 system // Frolov L. A., Pivovarov A. A., Baskevich A. S., Kushneriev A. I. // Russian Journal of Applied Chemistry. 2014. Vol. 87, Issue 8. P. 1054–1059. doi: https://doi.org/10.1134/s1070427214080084

6. Hydration mechanisms of hybrid cements as a function of the way of addition of chemicals // Fernández-Jiménez A., García-Lodeiro I., Malteses O., Palomo A. // Journal of the American Ceramic Society. 2019. Vol. 102, Issue 1. P. 427–436. doi: https://doi.org/10.1111/jace.15939

7. Recycling Industrial By-Products in Hybrid Cements: Mechanical and Microstructure Characterization // Garcia-Lodeiro I., Taboada V. C., Fernández-Jiménez A., Palomo A. // Waste and Biomass Valorization. 2017. Vol. 8, Issue 5. P. 1433–1440. doi: https://doi.org/10.1007/s12649-016-9679-x

8. Effect of mix design inputs, curing and compressive strength on the durability of Na2SO4-activated high volume fly ash concretes // Velandia D. F., Lysnadle C. J., Pruv J. L., Ramirez F. // Cement and Concrete Composites. 2018. Vol. 91. P. 11–20. doi: https://doi.org/10.1016/j.cemconcomp.2018.03.028

9. Design of the composition of alkalai activated portland cement using mineral additives of technogenic origin // Krivenko P., Petrovaplovskyi O., Vozniuk H. Development of mixture design of heat resistant alkalai-activated aluminosilicate binder-based adhesives // Construction and Building Materials. 2017. Vol. 149. P. 248–256. doi: https://doi.org/10.1016/j.conbuildmat.2017.05.138

10. Design of the composition of alkalai activated portland cement using mineral additives of technogenic origin // Krivenko P., Petrovaplovskyi O., Kovalchuk O., Lapovska O., Pasko A. // Eastern-European Journal of Enterprise Technologies. 2018. Vol. 4, Issue 6 (94). P. 6–15. doi: https://doi.org/10.15387/1729-4061.2018.140532

11. Development of alkali activated cements and concrete mixture design with high volumes of red mud // Krivenko P., Kovalchuk O., Pasko A., Crosby T., Hult M., Lutter G. et al. // Construction and Building Materials. 2017. Vol. 151. P. 819–826. doi: https://doi.org/10.1016/j.conbuildmat.2017.06.031

### 6. Conclusions

1. We have investigated the mineralogical composition of alkalai-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 alkalai-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.
14. Geopolymers for immobilization of Cr$^{6+}$, Cd$^{2+}$, and Pb$^{2+}$ / Zhang J., Provis J. L., Feng D., van Deventer J. S. J. // Journal of Hazardous Materials. 2008. Vol. 157, Issue 2-3. P. 587–598. doi: https://doi.org/10.1016/j.jhazmat.2008.01.053

15. Bernal S. A., Provis J. L. Durability of alkali-activated materials: Progress and perspectives // Journal of the American Ceramic Society. 2014. Vol. 97, Issue 4. P. 997–1008. doi: https://doi.org/10.1111/jace.12831

16. Kropyvnytska T., Semeniv R., Ivashchyshyn H. Increase of brick masonry durability for external walls of buildings and structures // MATEC Web of Conferences. 2017. Vol. 116. P. 01007. doi: https://doi.org/10.1051/matecconf/201711601007

17. The effect of structural characteristics on electrical and physical properties of electrically conductive compositions based on mineral binders / Pluhin O., Plugin A., Plugin D., Borziak O., Dudin O. // MATEC Web of Conferences. 2017. Vol. 116. P. 01013. doi: https://doi.org/10.1051/matecconf/201711601013

18. The Development of Alkali-activated Cement Mixtures for Fast Rehabilitation and Strengthening of Concrete Structures / Pavel K., Oleg P., Hryhorii V., Serhii L. // Procedia Engineering. 2017. Vol. 195. P. 142–146. doi: https://doi.org/10.1016/j.proeng.2017.04.536

19. Radioactivity and Pb and Ni immobilization in SCM-bearing alkali-activated matrices / Alonso M. M., Pasko A., Gascó C., Suarez J. A., Kovalchuk O., Krivenko P., Puertas F. // Construction and Building Materials. 2018. Vol. 159. P. 745–754. doi: https://doi.org/10.1016/j.conbuildmat.2017.11.119

20. Krivenko P., Petropavlovskii O., Vorozhek H. Alkaline aluminosilicate-based adhesives for concrete and ceramic tiles // Revista Romana de Materiale / Romanian Journal of Materials. 2016. Vol. 46, Issue 4. P. 419–423.

21. Slag-Based Cements That Resist Damage Induced by Carbon Dioxide / Ke X., Criado M., Provis J. L., Bernal S. A. // ACS Sustainable Chemistry & Engineering. 2018. Vol. 6, Issue 4. P. 5067–5075. doi: https://doi.org/10.1021/acssuschemeng.7b04730

22. The efficiency of plasticizing surfactants in alkali-activated cement mortars and concretes / Runova R., Gots V., Rudenko I., Konstantynovskiy O., Lastivka O. // MATEC Web of Conferences. 2018. Vol. 230. P. 03016. doi: https://doi.org/10.1051/matecconf/201823003016

23. From NORM by-products to building materials / Labrincha J., Puertas F., Schroyers W., Kovler K., Pontikes Y., Nuccetelli C. et. al. // Naturally Occurring Radioactive Materials in Construction. 2017. P. 183–252. doi: https://doi.org/10.1016/b978-0-08-102009-8.00007-4

24. Design of Rapid Hardening Quaternary Zeolite-Containing Portland-Composite Cements / Sanitsky M., Kropyvnytska T., Kruts T., Hopyrnyk O., Geyik I. // Key Engineering Materials. 2018. Vol. 761. P. 193–196. doi: https://doi.org/10.4028/www.scientific.net/kem.761.193

25. Krivenko P., Kovalchuk O., Pasko A. Utilization of Industrial Waste Water Treatment Residues in Alkali Activated Cement and Concretes // Key Engineering Materials. 2018. Vol. 761. P. 35–38. doi: https://doi.org/10.4028/www.scientific.net/kem.761.35

26. Analysis of plasticizer effectiveness during alkaline cement structure formation / Kryvenko P., Runova R., Rudenko I., Skorik V., Omelchuk V. // Eastern-European Journal of Enterprise Technologies. 2017. Vol. 4, Issue 6 (88). P. 35–41. doi: https://doi.org/10.15587/1729-4061.2017.106803

27. Efficiency of Redispersible Polymer Powders in Mortars for Anchoring Application Based on Alkali Activated Portland Cements / Rudenko I. I., Konstantynovskiy O. P., Kovalchuk A. V., Nikolainko M. V., Obrensky D. V. // Key Engineering Materials. 2018. Vol. 761. P. 27–30. doi: https://doi.org/10.4028/www.scientific.net/kem.761.27

28. Runova R. F., Kochevyh M. O., Rudenko I. I. On the slump loss problem of superplasticized concrete mixes // Admixtures – Enhancing Concrete Performance. 2005. P. 149–156.

29. Shrinkage Behavior of Alkali-Activated Slag Cement Pastes / Omelchuk V., Ye G., Runova R., Rudenko I. I. // Key Engineering Materials. 2018. Vol. 761. P. 45–48. doi: https://doi.org/10.4028/www.scientific.net/kem.761.45

30. Use of a highly dispersed chalk additive for the production of concrete for transport structures / Borziak O., Chepurna S., Zidkova T., Zhyhlo A., Ismagilov A. // MATEC Web of Conferences. 2018. Vol. 230. P. 03003. doi: https://doi.org/10.1051/matecconf/201823003003