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PROSPECTS OF USING THE POLYMETALLIC ORE PROCESSING WAIST FOR PRODUCING HARDENING MIXTURES

Purpose. Justification of possibility to create the hardening mixtures with filler based on tailings of the Akshatau mining and processing complex for strengthening the quarry benches, inter-chamber pillars and excavation roofs and producing building materials.

Methodology. The complex approach is applied including experimental methods of physical and chemical and mechanical analysis of the phase composition and properties of ore processing wastes. The practicability of using the tailings of polymetallic ore processing as an inert filling of hardening mixtures is estimated; the compressive and bending strength of samples is determined after the mixture solidification as well.

Findings. Based on X-ray phase analyses, differential thermal and chemical analyses, the ore tailings composition was determined. The optimal qualitative composition of the hardening mixture with specified rheological and strength properties, as well as the technological mode of its preparation, have been determined.

Originality. The peculiarities of hydration processes in the cement-water-limestone system are clarified and a new formulation of a hardening mixture with specified rheological and strength properties have been developed.

Practical value. The proposed composition of hardening mixtures with filler based on ore processing waste is aimed at strengthening the fractured area of the rock mass. This increases the stability of rock openings and provides safety of mining. The involvement of ore processing waste in the production of hardening mixtures and other building materials is a positive solution in terms of the disposal of these wastes. Reducing the amount of accumulated waste contributes to minimizing environmental risks in mining regions. The obtained results are significant for the construction industry. They provide the expansion and reproduction of the raw material base through using the waste of processing the ore of Akzhal deposit.

Keywords: *Akzhal deposit, carbonate rocks, polymetallic ore, waste of ore processing, tailings use, hardening mixture, filler, rocks, excavation stability*

Introduction. It is known that significant volumes of overburden rock, mineral processing wastes and slags have been accumulated in the mining regions of the world including Kazakhstan. According to modern estimations, over 50 billion tons of industrial wastes have been accumulated at the enterprises of mining complex of Kazakhstan which occupies vast territories of more than 150 square kilometers. Each year the amount of industrial waste increases by about 1.5 billion tons. Such huge amount of wastes creates a real technogenic threat to the environment of constantly increasing scale. Large areas allocated for tailing dumps are excluded from the scope of rational environmental management. Harmful substances contained in the tailings are released into the atmosphere. Polluted wastewater enters water basins while dried surface areas become sources of dust. Despite the currently developed technologies of the further use of mining and mineral processing wastes, the involvement level of this raw material in the production remains low [1].

At the same time, rising scale of construction throughout the world requires a significant amount of raw minerals for the construction materials industry. Intensification in this direction is possible by the use of industrial waste instead of primary natural resources. The expansion of the mineral resource base for the production of construction materials can be ensured not only by searching for new deposits of non-metallic minerals but also by involving technogenic wastes in the production in order to reduce the cost of construction materials.

The use of mining waste to obtain building materials is, of course, one of the priority areas for the development of mining regions' economy.

Analysis of existing solutions for the use of technogenic raw materials in the construction materials industry. The review of research works in this area shows that significant world experience has been gathered concerning the use of technogenic mineral raw materials in the production of new construction materials. The authors of articles [2, 3] show that the use of mining solid wastes in the building materials industry could be more economical than the production of building materials based on the special extraction of mineral raw materials. Thus, mining wastes find application in bricks [4], concrete [5], and glass ceramic [6] production. Efficient binding components have been developed for the mortar mixes [7] using wastes from the processing of substandard raw materials. There are building materials obtained from the overburden rocks of the Tatar rare metal deposit, in which ore dressing wastes were used as a lightweight concrete filler for the plaster mortars, as well as being used in environmental protection measures [8]. Similar studies on the use of mining waste for obtaining building materials and products are being carried out in the Republic of Kazakhstan. Thus, the expansion of the mineral resource base for the building materials industry can be ensured not only by searching for new deposits of non-metallic minerals but also by involving the technogenic non-metallic wastes into production. At the same time, majority of the authors of the above-mentioned works note that the industrial processing of technogenic raw materials (wastes, overburden and enclosing rocks), that are similar in composition to the natural ones and used in traditional areas, practically does not differ from the industrial processing of natural mineral raw materials.

The paper [9] considers the use of wastes from copper ore processing at "Kazakhmys Corporation" LLP for the production of foam-glass-crystalline materials with high performance properties. Scientists of the Central Laboratory for Certification of Building Materials of Kazakhstan have developed a new environmentally friendly technology for neutralization of granular phosphorus slag from hazardous gases with the production of competitive binding and building products [10]. New schemes for extraction of metals from the tailings of ferrous and non-ferrous metallurgy, as well as coal processing, are given in [11]. It has been proven that the mechanical activation method provides extracting metals from tailings to the level of sanitary requirements, which makes it possible to use secondary tailings without restrictions for manufacturing concrete products.

The article [12] assesses the properties of concrete whose composition has been modified by replacing sand with iron ore tailings. This method solves both the problem of the lack of natural sand and the simultaneous utilization of industrial wastes. Studies on the chemical composition of tailings from the iron ore mining in Zibo city showed that it is very close to the composition of natural sand (SiO_2 up to 70 %). This indicates that it can be used for concrete production. The authors determine mechanical properties of concrete samples with different percentages of iron ore wastes. It is shown that 35 % replacement of natural aggregate with iron ore mining waste is optimal for ensuring the proper bearing capacity of the concrete. With a 35 % replacement of sand with iron ore tailings, the concrete properties are equivalent to those of natural aggregate concrete. This confirms the feasibility of using wastes in engineering applications.

In paper [13], the authors present the characteristics of cementing products of various consistency, in which flotation concentrates based on gold, copper, and copper sulfide are used. In some experiments, sand was also replaced with flotation tailings. The results showed that blends containing 10 % wastes with 15.0–37.5 % water by weight produced cemented materials with a uniaxial compressive strength (UCS) in the range of 0.4–3.0 MPa after 28 days of curing. The authors consider this a very positive result for the use of the developed mixtures for load-bearing building structures.

It follows from the above review that considerable practical experience has been accumulated in the use of wastes from mining and metallurgical production for the creation of construction materials. However, the problem of selecting the formulation of mixtures and ways to improve their performance properties remains relevant for various areas of application of hardening mixtures. Most of the mentioned studies are aimed at achieving sufficient strength of materials containing wastes from mining and ore processing. This task is a priority for most of the above-mentioned studies and remains unresolved since it relates to different mineralogical and chemical composition of wastes, their degree of fineness, and other factors. The selection of the optimal ratios of components in the mixture in each specific case of the use of wastes from mining and ore dressing requires additional research.

It should be noted that the production of hardening solutions using the mentioned wastes is promising in the mining industry. In the article [12] cited above, the authors pay great attention to the problem of backfilling worked-out space in the mines and indicate that in this area the use of processing tailings is the most appropriate. In addition, ensuring the stability of roadways that were excavated inside the rocks with high natural and technogenic fracturing requires the use of hardening materials. This problem is acute in the extraction of polymetallic ores at the Akzhal mine (Shet district of the Karaganda region, Kazakhstan). There, a high fracturing is typical both for the sides of the quarry and for the rock through which underground galleries have been laid (Fig. 1). Despite the strong rocks enclosing the ore veins (sandstones and limestones of the Famennian and Tournaisian age) the mine field is disturbed by a large number of faults of various orientations as a result of tectonic processes, since the deposit is confined to the crushing zone in the core of the anticline. Among these faults, large geological discontinuities and small feathering cracks have been identified. The presence of joints sharply reduces the strength of rocks [14]. Examinations of underground galleries have shown that systems of steeply dipping joints have the most negative impact on the stability of excavations. If there are systems of intersecting joints in rock mass that provide rock falls and creating wedges, the operations of underground workings become impossible. In the open part of the mine the decrease in the cohesion of the rocks that form the benches of the open pit leads to the unpredictable development of sliding surfaces and the stability loss of the quarry slopes.

One of the solutions to the problem is to strengthen fractured rocks by injecting hardening mortar through a system of vertical and inclined wells until the rock mass is completely saturated and joints are filled. In this case, the hardening solution must simultaneously satisfy several requirements including sufficient viscosity when moving through the injection pipes and sufficient strength after hardening [15]. Besides, an important factor is the cost of such work which largely consists of the mixture components cost. A logical solution to the problem is the use the processes and materials already involved in the extraction and processing of ores at this particular enterprise. Moreover, the accumulation of large amounts of nonmetallic rock and processing tailings is an equally acute problem at the Akzhal mine and the Akshatau mining and processing plant, which receives raw materials from the Akzhal mine.

In relation to the foregoing, this article is focused on assessing the possibility of using the wastes from the processing of polymetallic ores from the Akzhal deposit to obtain hardening mixtures for various functional purposes including using it for backfilling the worked- out space in the mines and strengthening rock openings disturbed by the cracks.

To achieve this goal, the main characteristics of ore mining wastes at the Akzhal mine and ore processing wastes at the Akshatau mining and processing plant were studied.

The main ore minerals of the Akzhal deposit are sulfides (sphalerite, galena, chalcopyrite, pyrite). Associated elements are gold, silver, cadmium, indium, thallium, gallium, selenium, tellurium.

The processing of ores at the Akshatau Mining and Processing Plant is carried out by hydroclassification, electromagnetic separation and flotation. The plant produces the following types of concentrates: tungsten, molybdenum, bismuth, tin, but lead and zinc concentrates make up the bulk of the production. The average concentration of ores is such that the yield of ore tailings reaches almost 93 % of the total mass of the ore, and the yield of lead and zinc concentrates are 0.44 and 6.59 %, respectively.

Thus, as mentioned above, the tailings of sulfide ores are enormous. For its storage, special hydrotechnical structures (tailing dumps) have been designed. It should be noted that the tailing dump is not only one of the most expensive facilities of the enrichment complex but also a concentrator of technical and environmental risks. The in-service life of the tailing

Fig. 1. Measurement of the intensity of the rock mass fracturing

dumps is limited and many of them have already been fulfilled or will be fulfilled in the coming years. Waste is a finely dispersed and easily blown off material, therefore, when dried it becomes a source of dust. Besides, there are risks associated with the accumulation of a critical amount of technogenic water, namely: the destruction of dams, water breakthroughs and flooding of territories, violation of the surrounding ecosystem. The more water is required to process the ore, the more problems arise with the maintenance of the tailings. At the same time, water is a scarce resource needed in many production cycles. In particular, an important element in the creation of hardening mortars is the mixing of solid components with water. Therefore, the studies presented in this article are focused on the study into not only the composition of solid enrichment wastes, but also technogenic water used in the ore dressing.

Samples of ore dressing wastes, as well as process water left after ore processing, were examined under laboratory conditions.

Research methods. Studies on the waste composition of the Akshatau processing plant were carried out using modern physical and chemical methods and appropriate certified equipment from various manufacturers. To study the phase composition of the waste, the methods of X-ray phase, as well as differential thermal and chemical analyzes were used.

X-ray phase analysis (XPA) was performed on a DRON-3M X-ray unit (RF). X-ray diffraction analysis was carried out with a JCXA-733 Superprobe microanalyzer (Japan) with adapted software. Waste structure was studied using a Leica ICH DM2500 laboratory polarizing microscope (Switzerland), equipped with a powerful 100 W illuminator, which allows efficient work with differential interference contrast. Differential thermal analysis (DTA) was carried out on a MOM-1500 D derivatographic instrument (Hungary). A PMT-3 microhardness tester (RF) was also used.

Granulometric analysis was performed by two methods, which are sieve analysis using a multi-frequency sieve analyzer MSA W/D-200 Kroosh Technologies Ltd. and granulometric analysis using a Helos-KR diffraction laser as well as particle size analyzer with Quixel attachments.

The results of studying ore processing waste at the Akshatau mining and concentration plant. On the basis of the DRON-3M multifunctional automatic X-ray diffractometer, the X-ray pattern and diffraction characteristics of samples taken from polymetallic ore waste were obtained (Fig. 2).

The radiograph shows that all the taken samples include calcite, since the graph shows reflections (peaks) characteristic of $CaCO_3$, with interplanar distances, d/n, Å: 3.8665; 3.3498; 3.0404; 2.8446; 2.496; 2.2847; 2.0952; 1.9127; 1.77; 1.6287; 1.60; 1.5236; 1.4393.

Based on chemical analysis, it was found that the oxide composition of the tailings is represented by the following individuals, %: CaO — 54,3; CO_2 — 40,5; SO_3 — 2,3; SiO_2 — 1,5; MgO — 1,4; $Fe[S_2]$ — 0,13 %. The chemical analysis of tailing processing is supplemented by differential thermal analysis (DTA), which is used to record phase transformations in a sample. In accordance with the physical concept of the method, samples of sulfide mineral tailings were heated in a MOM-1500 D derivatographic device (heating mode was linear and heating rate was 100 C/min). The temperature difference between the test sample and the reference sample was recorded. The aluminum oxide was used as the reference sample as it is an inert substance and does not have phase transformations under the conditions of this experiment. A significant temperature difference arises from the endo- or exothermic transformations in the tested sample. The magnitude of the thermal effects in thermal transformations correlates with the mineral content in the mixture, which makes it possible to determine the composition of polymineral mixtures.

When studying the tailings of sulfide ores, the derivatogram (Fig. 3) shows only one endothermic effect at 950 °C, which represents the decomposition of calcite $CaCO_3$ into calcium oxide CaO and carbon dioxide CO_2 in accordance with the equation: $CaCO_3 = CaO + CO_2\uparrow$. The weight loss reaches more than 305 % of the sample weight.

Granulometric analysis showed that the content of grains that are larger than 10 mm is 3.26 %, the content of grains that are larger than 5 mm is 1.96 % and the content of grains that are less than 0.16 mm is 46.3 %. The fineness modulus of the sand obtained after the processing of raw materials is 0.83. This allows us to attribute it to very fine sands, which are suitable for the preparation of plaster mixtures in construction.

Thus, the studied waste of ore processing is a finely ground product that does not require additional grinding before use. This once again indicates the expediency of using ore dressing waste as a filler for hardening mixtures. In addition, studies showed that the process of ore dressing ensures the homogeneity of the material both in terms of chemical and mineralogical composition.

It is these artificial fine sands that can be used in the manufacture of injection solutions to fill cracks in rock openings. The bulk density of the obtained material is 1,515 kg/m^3, the true density is 2.74 g/cm^3, and the voidness reaches 44.7 %.

The specific effective activity of natural radionuclides is also determined for the material obtained after ore processing. It is 120 Bq/kg (becquerel/kg), which does not exceed the requirements of regulatory documents (in accordance with the norms of Kazakhstan, this value should not exceed 370 Bq/kg).

Thus, the conducted studies show that the solid tailings of polymetallic ore enrichment from JSC "Akshatau" contain a large amount of calcite.

The chemical composition of this raw material, namely, the presence of 54.6 % calcium oxide (CaO) and 2.5 % silicon

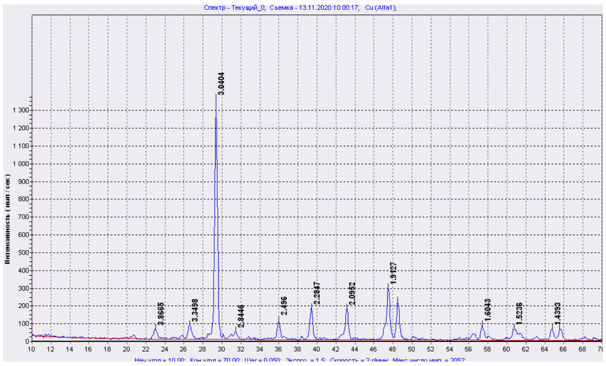

Fig. 2. X-ray graph of the tailings from JSC "Akshatau"

Fig. 3. Derivatogram of the sulfide ore tailings from JSC "Akshatau"

dioxide (SiO_2) allows it to be used as a filler in building mixtures for various purposes, including for strengthening fractured rocks.

Results of studying technogenic process water and water from the mine. The following characteristics of the selected water samples were obtained in laboratory conditions:

- alkalinity for mine water is 0.45 mg-eq/l, for process water this characteristic is 0.8 mg-eq/l;
- hardness for mine water is 11 mg-eq/l, for technological water this characteristic is 12 mg-eq/l;
- acidity index (pH) for mine water was 7.5, for process water this characteristic was 8.3.

Mine water is visually transparent while waste process water is cloudy. This fact indicates that in the process water there are insoluble particles of tailings from the processing of sulfide ores from the Akzhal deposit, which consist mainly of calcite $CaCO_3$.

At the same time, presence of calcite can affect the properties of mixtures, for the binding of which the technogenic water that remains during ore processing, could be used.

The possibility of using the studied processing wastes as a filler in hardening mixtures is due to the specifics of the interaction of cement with water and filler.

Peculiarities of hydration processes in the hardening mixture. The amount of adhesion between the surfaces of cement stone and filler in hardening mixtures depends both on the morphology of new hydrate formations and on the type of filler. During the hydration of cement in the cement stone, the following hydrated phases mainly occur*:* CSH, $3CaO \times Al_2O_3 \times 6H_2O$, $Ca(OH)_2$, $3CaO \times Al_2O_3 \times 3CaSO_4 \times 31H_2O$, as well as others (total 17 items). For the processes under consideration, it is the four marked phases that are of greatest importance.

Fillers (small and large) for embedded and spray mortars can be granite, quartz, feldspar, carbonate and others. At the same time, it is carbonate fillers that provide the best adhesion in hardening systems. Quartz, feldspar and granite filler have this property to a lesser extent, according to the order of their enumeration above.

Therefore, the use of fillers from processing tailings containing a significant amount of calcite will provide good adhesion between the surfaces of the cement stone and the filler, and therefore, favorably affects the strength properties of hardened embedded and sprayed mortars. Calcite has a positive effect not only on adhesion to cement stone but also on all hydration processes in hardening silicate systems [16, 17]. The dispersity of carbonate materials during surface interaction is of no fundamental importance. In any case, there is a chemical interaction between carbonates and hydrate cementing substances, which is very important for the strength and durability of embedded and spray mortars based on these fillers. It is known that in the presence of calcite, the hardening of the hydrated cement system is accelerated in the initial periods, while its activity increases by 2.5 times [15]. This is due to the appearance of an additional amount of hydration products as a result of the catalytic effect of limestone on the cement hydration process.

The positive effect of carbonates of alkaline earth materials (calcite, magnesite and dolomite) on the processes of hydration, hardening of silicate hydrating systems and the synthesis of their strength is due to the following functions:

- catalytic action;
- increase in the pH of the hardening environment;
- positive change in the conditions of crystallization of hydration products.

In addition, the carbonate surface can be a center of crystallization of hydration products and a substrate for new formations. In this case, the higher the orientation of the growing crystals of hardening products (epitaxy) on the surface of the substrate, the greater the strength of the slag stone.

Selection of the solution's composition for strengthening fractured rocks based on ore processing wastes. The performed studies made it possible to develop a solution formulation in which the above-described tailings of polymetallic ores processing from the Akzhal deposit were used as a filler. Additionally, it is proposed to introduce into the solution a dry plasticizer Neolit 400, which is produced by Neochim company based on polycarboxylate copolymers. This additive has a high water-reducing ability, which makes it possible to reduce the water-binding ratio in the mixture by more than 20 %. With a decrease in the water-binding ratio, the durability and density of the developed solution increase. At the same time, creep deformations and shrinkage decrease during the curing of mortars. Plasticizer Neolit 400 is well compatible with Portland cements.

The formulation of the hardening mixture (Table 1) based on cement, tailings and plasticizing additives was developed in the laboratory by setting up a multifactoral experiment.

The percentage ratio was varied for the components, which were loaded into a laboratory mixer and thoroughly mixed with the addition of water. At the same time, both ordinary water from the water supply system and mine water, as well as process water used in the process of ore dressing, were used for mixing.

The experiment's matrix assumed the variation of three variables (the content of cement, filler and plasticizer) at three levels: minimum, maximum and average values. The output variables were the strength properties of the tested material.

The minimum required number of trials to perform a full factorial experiment is determined by the formula

$$N = k^p,$$

where p is the number of variating variables; k is the number of levels. Thus, the number of trials was 33, which equals 27 trials.

Samples of 4 × 4 × 16 cm were made out of the mixture and compacted on a vibrating platform for 45 seconds. After a day, the samples were removed from the molds and stored in humid conditions for 28 days (reference value). Then the samples were tested on a hydraulic press to determine the physical and mechanical properties. The test results are shown in Table 2.

The suitability of mine and process water as a water filler of the proposed mixture was tested in accordance with the technical requirements of the state standard GOST 31108-2016 of Kazakhstan. As a standard, we took a mortar mixture mixed with ordinary water from the water supply system. The results of the experiment showed the following:

- hardening of the cement paste when using technogenic water occurs in a time interval from 160 to 170 minutes, when using ordinary water this process takes 180 minutes. That means that the use of technogenic water containing calcite accelerates the hardening process, which is a positive effect;
- the water demand of the cement paste when using technogenic water is slightly higher (from 29.5 to 31.0 %) than when using ordinary water (29.0 %);
- the rate of strength development of cement stone, regardless of the type of water mixing, is identical; however, the strength of cement stone when using process water from the processing plant is 19 % higher than when using ordinary and mine water.

It follows from the foregoing that mine and process water may well replace ordinary water as a thickener for mortar and concrete mixtures. This will provide significant savings in water resources and simplify the logistics in the manufacture of the hardening mixture directly at the working sites of a quarry or mine.

It follows from Table 2 that the material obtained after hardening has a strength of at least 35 MPa. This makes it pos-

Table 1

Quantitative composition of the proposed hardening mixture

Component	Cement	Polymetallic ores processing tailings	Plastificator Neolit 400	Water
Content, %	from 32 to 37	from 47 to 52	from 0.11–0.16	Else

Table 2

Physical and mechanical properties of the samples obtained by curing the solution

Number of mixture	Formulation of mixture, mass %				Properties		
	Cement	Tailings from processing plants	Neolit 400	Water	Ultimate compressive strength, MPa	Bending strength, MPa	Cone draft, mm
1	32	52	0.16	15.9	32.4	4.3	150
2	33.4	49.3	0.13	16.3	35.7	5.1	146
3	37	47	0.11	16.9	36.9	5.7	142

sible to use it for filling voids in rocks, for example, in disturbed inter-chamber pillars or in the roof of the gallery in places of rock falls. The addition of a plasticizer ensures sufficient mobility of the mixture. This allows it to be used for injection into a fractured rock mass in order to stabilize rock deformations. The same properties make it possible to use a hardening solution for spraying on the surface of rock openings.

The technical novelty of the created solution was confirmed by the patents of the Republic of Kazakhstan for the invention [18].

An analysis of work to maintain underground excavations under complicated mining and geological conditions [19, 20] showed that shotcrete is an effective method for ensuring stability. High technological and technical and economic indicators of lined roadways are achieved due to the correctly selected composition of the concrete mix for shotcrete, taking into account the specifics of underground operations. Therefore, we are currently working on a feasibility study for the use of the regular and new recommended composition of shotcrete mortar.

Conclusions.

1. Laboratory studies based on X-ray phase, differential-thermal, and chemical research showed that the waste from the processing of the polymetallic ores at the Akzhal deposit mainly contains $CaCO_3$ calcite. This fact makes it possible to use the studied wastes as a filler in the creation of hardening solutions, since calcite has a positive effect on all hydration processes in hardening silicate systems and provides good adhesion to the cement stone.

2. Studies on the granulometric composition of solid waste showed that this is a finely granulated product that does not require additional grinding before use. This once again indicates the expediency of using ore processing wastes as a filler for hardening mixtures.

3. On the basis of the performed analysis, a hardening mixture was developed with the following mass ratio: cement is up to 32–37 %, tailings of processing plants are up to 47–52 %, Neolit 400 superplasticizer is up to 0.11–0.16 %, the rest is water.

4. It is shown that the process water from the processing plant can be used for thickening the mixture. The positive effect is a reduction in the setting time of the cement paste by 10–12 % compared to using ordinary water from the water supply system. The strength of the cement stone when using process water from the processing plant is 19 % higher than when using ordinary and mine water.

5. The material obtained after hardening has a strength of at least 35 MPa. This allows it to be used for spraying and filling voids in the rock. The addition of a plasticizer ensures sufficient mobility of the mixture. This allows it to be used for injection into a fractured rock mass in order to stabilize rock deformations.

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Перспективи використання відходів збагачення поліметалевих руд для отримання твердіючих сумішей

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Мета. Обґрунтування можливості отримання сумішей, що твердіють, із заповнювачем на основі хвостів збагачення Акшатауського гірничо-збагачувального комплексу для зміцнення бортів кар'єрів, порушених міжкамерних ціликів, стволів і виробництва будівельних матеріалів.

Методика. Основою рішення є комплексний підхід, що включає експериментальні методи фізико-хімічного й фізико-механічного аналізу фазового складу структури та властивостей відходів збагачення. Оцінюється доцільність використання відходів збагачення поліметалевих руд як інертне заповнення сумішей, що твердіють, а також визначається міцність на стиск і вигин зразків суміші після її затвердіння.

Результати. На основі рентгенофазового, диференціально-термічного та хімічного аналізів визначено склад відходів збагачення поліметалевих руд. Встановлено оптимальний якісний і кількісний склад твердіючої суміші із заданими реологічними й міцнісними властивостями, а також технологічний режим її приготування.

Наукова новизна. Розкриті особливості гідратаційних процесів у системі цемент-вода-вапняк, на основі чого запропонована нова рецептура твердіючої суміші із заданими реологічними й міцнісними властивостями.

Практична значимість. Твердіюча суміш із заповнювачем на основі хвостів збагачення поліметалевих руд призначена для зміцнення тріщинуватих ділянок гірського масиву. Це підвищує стійкість породних оголень і безпеку робіт. Залучення відходів збагачення у виробництво твердіючих сумішей та інших будівельних матеріалів є позитивним рішенням щодо утилізації цих відходів. Зменшення обсягів накопичених відходів сприяє мінімізації екологічних ризиків у гірничо-добувних регіонах. Значимість отриманих результатів для будівельної галузі полягає в розширенні й відтворенні сировинної бази будівельних матеріалів за рахунок використання відходів збагачення руди Акжалського родовища.

Ключові слова: *Акжалське родовище, карбонатні породи, поліметалеві руди, відходи збагачення, використання відходів, твердіюча суміш, заповнювач, гірські породи, стійкість виробок*

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