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Satbayev University

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
НАУК РЕСПУБЛИКИ
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INDUSTRIAL WASTE RECYCLING – ONE OF THE KEY DIRECTIONS OF BUSINESS DEVELOPMENT

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Abstract. Article discusses preliminary work results carried out by the Kazakh National Research Technical University (KazNIRU) named after K.I. Satpayev together with the Central Laboratory for Certification of Building Materials (CLCBM) on resource saving and recycling of industrial waste to obtain demanded building materials. Processing of industrial wastes (wastes of enrichment and processing, overburden and enclosing rocks), close in composition to natural and used in traditional areas, practically does not differ from the industrial processing of natural mineral raw materials. Creation of efficient technologies for processing of technogenic raw materials is urgent task, which make it possible to obtain competitive products from it for various industries. Utilization of waste from mining and metallurgical complexes makes it possible to reduce technogenic load on the environment and ensure rational use of secondary raw materials. Possibility of obtaining solutions for strengthening fractured rocks and building structures has been studied. Study results of wastes of the Akshatau Mining and Processing Plant are presented and the possibility of using them to strengthen fractured rocks is confirmed. With the help of strengthening, it is possible to slow down processes of slacking and sloughing of rocks, to prevent ledges collapse and rocks sloughing from surface of slopes. Rock mass hardening in the weakened areas is achieved by substances injection into array cracks, which, after hardening and setting of rock, significantly increase its resistance to shear. The most widespread among hardening methods is cementation during mine workings (underground structures) in fractured rocks. Significance of obtained results for construction industry lies in the expansion and reproduction of raw material base of building materials industry through use of MMC waste (concentration tailings) and development of resource-saving technologies.

Keywords: deposits development, open-pit, mine, rock massif collapse, concentration plant, strengthening, mining waste, environmental safety, building materials, solutions

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ӨНДІРІСТІК ҚАЛДЫҚТАРДЫ ҚАЙТА ӨҢДЕУ – КӘСІПКЕРЛІКТІ ДАМЫТУДЫҢ НЕГІЗГІ БАҒЫТТАРЫНЫҢ БІРІ

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Аннотация. Мақалада Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университетінің (ҚазҰТЗУ) Құрылыс материалдарын сертификаттау орталық зертханасымен (ЦЕЛСИМ) бірігіп, ресурс үнемдеу және қажетті құрылыс материалдарын шығаруда техногендік қалдықтарды кәдеге бойынша жүргізіп жатқан жұмыстарының алдын ала нәтижелері келтірілген. Құрамы бойынша табиғиға жақын және дәстүрлі аймақтарда қолданылатын өнеркәсіптік қалдықтарды (байыту және өңдеу қалдықтары, аршу және қоршама тау жыныстары) өңдеу табиғи минералды шикізатты өнеркәсіптік өңдеуден іс жүзінде ерекшеленбейді. Техногендік шикізатты өңдеудің одан әр түрлі салалар үшін бәсекеге қабілетті өнім алуға мүмкіндік беретін тиімді технологияларын жасау кезек күттірмейтін мәселе. Тау-кен металлургиялық кешендердің қалдықтарын кәдеге жарату қоршаған ортаға техногендік жүктемені азайтуға және қайталама шикізатты ұтымды пайдалануды қамтамасыз етуге мүмкіндік береді. Жарықшақты тау жыныстары мен жер асты құрылымдарын нығайту үшін ерітінділер алу мүмкіндігі зерттелді. «Ақшатау тау-кен байыту комбинатының» қалдықтарын зерттеу нәтижелері келтірілген және оларды жарықшақталған тау жыныстарын нығайту үшін ерітінділерге пайдалану мүмкіндігі дәлелденді. Нығайтудың көмегімен тау жыныстарының үгілу және төгілу процестерін бәсеңдетуге, карьер беткейлердегі тау жыныстарының құлауын және төгілуін болдырмауға болады. Карьердің әлсіреген учаскелеріндегі тау жыныстары массивін беріктеу кен массивінің қатайғаннан кейін оның ығысуға деген төзімділігін арттыратын заттарды кен жарықшақтарына енгізу арқылы қол жеткізіледі. Осындай беріктеу әдістерінің ішінде ең кең таралғаны — жарықшақты тау жыныстарын (жер асты қазбаларындағы да) цементтеу

Түйінді сөздер: кен игеру, карьер, кеніш, тау-кен массивінің құлауы, жарықшақтар, байыту фабрикасы, беріктеу, тау-кен өнеркәсібінің қалдықтары, экологиялық қауіпсіздік, құрылыс материалдары, ертінділер

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ПЕРЕРАБОТКА ПРОМЫШЛЕННЫХ ОТХОДОВ – ОДНО ИЗ КЛЮЧЕВЫХ НАПРАВЛЕНИЙ РАЗВИТИЯ БИЗНЕСА

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Аннотация. В статье рассматриваются предварительные результаты работ, проводимые Казахским национальным исследовательским техническим университетом (КазНИТУ) имени К.И.Сатпаева совместно с Центральной лабораторией сертификации строительных материалов (ЦеЛСИМ) по ресурсосбережению и утилизации техногенных отходов для получения востребованных строительных материалов. Переработка промышленных отходов (отходы обогащения и переработки, вскрышные и вмещающие породы), близкого по составу к природному и используемого в традиционных направлениях, практически не отличается от промышленной переработки природного минерального сырья. Создание эффективных технологий переработки техногенного сырья, позволяющих получать из него конкурентоспособную продукцию для различных областей промышленности, является актульной задачей. Приведены результаты исследования отходов «Акшатауского горно-обогатительного комбината» и подтверждена возможность использования их для укрепления трещиноватых горных пород. С помощью укрепления можно замедлять процессы выветривания и осыпания пород, предупреждать обрушения уступов и осыпание пород с поверхности откосов. Упрочнение массива горных пород на ослабленных участках достигается введением в трещины массива веществ, которые после упрочнения и схватывания породы значительно повышают ее устойчивость к сдвигу. Наибольшее распространение среди методов упрочнения получила цементация при проведении горных выработок (подземных сооружений) в трещиноватых породах. Значимость полученных результатов для строительной отрасли заключается в расширении и воспроизводстве сырьевой базы промышленности строительных материалов за счет использования отходов ГМК (хвостов обогащения) и разработки ресурсосберегающих технологий.

Ключевые слова: разработка месторождений, карьер, рудник, обрушения горного массива, трещины, обогатительная фабрика, укрепление, отходы горного производства, экологическая безопасность ,строительные материалы, растворы

Introduction

At present, when intensity of human influence on the process of subsoil development of the Earth is enormous, principles laid down by Academician K.I. Satpayev in his teaching “On the integrated use of the subsoil wealth” sound more relevant than ever. Earth, subsoil and environment are common concern of mankind. Special part of this responsibility is assigned to scientists and specialists in the field of development of the earth's interior, designed to ensure their rational use and environmental safety.

Scale of impact of industrial waste on the environment is comparable to geological processes. Obviously, development of human society is impossible without interaction with environment, and, consequently, impact on nature without use of natural resources. However, urgent need for fundamental restructuring of modern environmental management technologies has become obvious, due to the manifestation of disparate environmental impacts of various industries. This is due to fact that sectoral division of responsibility for generated waste does not allow creating sufficiently effective system for integrated management of production waste, which ensures maximum possible use of industrial waste as additional materials (Baidzhanov et al., 2020: 4; Petlovanyi et al., 2019:14).

On the territory of the Republic, according to the State Cadastre, about 30 billion tons are stored in dumps, tailings and storage facilities of mining enterprises. industrial waste, including: 72 % – overburden and substandard ores, 20 % – tailings, 8 % – other waste. With annual output of industrial waste of 1 billion tons no more than 100 million tons are usefully used. The rest pollutes environment, gradually accumulating in it.

According to the data of the State control and supervision over natural resources, share of used waste in the republic is 18–20 %. For example, in 2007, percentage of waste disposal was 16 %, in 2008–18.98 %, and in 2009. – twenty %. However, this figure in the recent past in the industry of the former USSR was 29 %. It remains extremely low in comparison with world practice. In Western Europe (France, Germany, Italy, England) this figure is up to 58%, in North America (USA, Canada) – up to 63 %, in Japan – up to 87 %, China - up to 37 % (Information on the organization…2018: 154; Rysbekov et al., 2021: 4).

Thus, accumulated waste is, on the one hand, main environmental pollutants, and on the other hand, they are valuable products that are potentially suitable for processing and reuse to obtain commercial products with high added value.

In order to develop and implement effective environmental measures for waste management, it is necessary to have reliable information about their impact on natural ecosystems: surface and ground waters, air and land disturbance on an industry scale with an increasing volume of production. Generalized materials will allow obtaining objective information about ecosystems state in the region under study and identifying priority environmental measures, implementation of which will help reduce harmful impact on the environment.

Impact scale of wastes (technogenic mineral formations) of production on environment is comparable to geological processes. Technogenic mineral formations (TMF) are accumulations of waste from mining, metallurgical, energy and chemical industries, containing useful components or minerals.

The bulk of mining waste in Kazakhstan is generated in mining enterprises (73 %), processing plants (25 %) and metallurgical plants (2 %). According to modern estimates, the enterprises of the mining complex of Kazakhstan have accumulated over 30 billion tons of industrial waste and occupy vast territories (more than 150 square kilometers). Annually, amount of industrial waste increases by about 1.5 billion tons, and at the same time, level of use of TMF is currently low. Need for development (processing) of TMF is dictated by the fact that TMF occupy vast areas of easily blown off material and are a source of increased environmental risk for the regions of the MMC. Constant increase in the volumes of various types of waste generated in the mining and processing industry and their storage in storage facilities and the experience of using such objects in industry allows us to consider them as sources for obtaining secondary raw materials and building materials (Kuldeyev et al., 2020: 4; Jiang et al., 2017: 8).

Comparative analysis. Growth in the scale of construction in Kazakhstan requires a significant amount of minerals for building materials industry. Intensification in this direction is associated with the use of industrial waste instead of primary natural resources in order to reduce cost of building materials. Use of mining solid waste in building materials industry is more economical than production of building materials based on special extraction of mineral raw materials.

Review of existing scientific works in this area shows that there is significant world practice of conducting research on use of technogenic mineral raw materials. So, in the far abroad, mining wastes are used to produce bricks, concrete, etc. (Golik et al., 2015: 3; Lozynsky et al., 2018: 11).

With use of mining waste from processing of substandard raw materials, effective binders for preparation of building mixtures have been developed. Building materials were obtained from overburden rocks of the Tatar rare metal deposit in the Krasnoyarsk Territory, where concentrates were used as filler for lightweight concrete, for preparation of plaster mortars, and in environmental protection measures (Lygina et al., 2017 :5).

Similar studies on use of mining waste to obtain building materials are being conducted in the Republic of Kazakhstan. Scientists from Central Laboratory for Certification of Building Materials (CLCBM) have developed new environmentally friendly technology for neutralizing granular phosphorus slags from hazardous gases to obtain competitive binders and building products. The use of additives from tailings of polymetallic ores increases property of cement mortars for strengthening fractured rocks. It has been established that developed embedded mixtures with given high adhesion strength based on enrichment tailings contribute to the creation of waste-free technologies for processing mineral raw materials, reducing cost of both main industrial products and production of building materials, and solving environmental problem (Yestemesov et al., 2020: 9; Zhalgassuly et al., 2020: 6).

Thus, it can be argued that waste recycling is not only necessary condition for environment protecting, but also means of global resource and energy conservation.

Rational organization of waste processing process, combined with efficient modern equipment, makes it possible to obtain products from secondary raw materials with a cost of 2–2.5 times lower than for similar products from primary raw materials, with a comparable product quality.

The need to involve in production, namely tailings, is dictated by following circumstances:

production, namely tailings, is dictated by the following circumstances:

- service life of tailings is limited, filling of many has already been completed or will be completed in the coming years;

- tailings occupy vast territories and, due to fact that they are finely dispersed and easily blown off material, are source of increased environmental risk for the regions where mining and processing complexes operate (Yestemesov et al., 2022: 8).

Since enrichment waste is finely ground product that does not require additional grinding before use, this reduces economic costs. In addition, in the process of enrichment of ores, the homogeneity of the material is ensured both in terms of chemical and mineralogical composition.

One of enterprises where non-metallic rocks, enrichment tailings and waste waters are formed is Akshatau Mining and Processing Plant JSC, which receives raw materials from the Akzhal mine.

Research methods

Physical and chemical research. Identification of initial raw materials was carried out in accordance with requirements of physical and chemical analysis.

X-ray diffraction patterns were taken on modernized DRON-3M diffractometer using Cu-Kα — radiation with software. X-ray diffraction patterns of materials (samples) were obtained in the 2θ range (angles) from 10 to 70 °. Preparations for shooting were prepared as follows (sequentially):

Investigated substance (sample) was ground in agate mortar to state of powder;

Then prepared powder was poured into plexiglass cuvette, previously lubricated with petroleum jelly, and pressed a little;

For remove texture, excess powder was cut off with blade.

IR spectra were recorded on «Specord M-80» spectrophotometer (Germany) in the frequency range 4000-200 cm^{-1} and on Fourier spectrometer «TENSOR-2», manufactured by «BRUKER». The analysis used tablets with tungsten consentrate (KVG).

Physical and mechanical research. Cement tests were carried out in accordance with technical requirements of relevant standards. Granulometric composition — size modulus and grain size composition, physical property of tailings was determined in accordance with GOST 8736–2015 «Sand for construction work».

Specific effective activity of natural radionuclides was determined in accordance with the requirements of GOST 30108–94: « Materials and building products. Determination of effective activity of natural radionuclides».

Physical and mechanical properties of embedded mortars and their testing were determined according to GOST 28013–98: «Building solutions. General technical conditions» and GOST 5802–86 «Building solutions. Test methods»

Research results

Study of composition of waste from processing plant of the Akzhal mine was carried out using modern methods of physical and chemical research — X-ray, differential, thermal, petrographic, chemical and related equipment. To study phase composition of waste, methods of X-ray phase and differential thermal and chemical analyzes were used on the latest installations of leading countries (Russia, Germany, Japan, Switzerland).

Results of workings survey at the Akzhal mine (in quarry and underground horizons) showed that largest number of fallouts is associated with fractured rocks, and volume of fallouts increases as workings stand. Observations of workings passed through fractured rocks revealed that they are stable for a month. After two or three months, stabs up to 10–15 cm in size are formed. Stinging and falls develop within six months, roof collapse occurs in form of domes. This dramatically increases volume and labor intensity of tunneling operations, as well as the cost of fixing and repairing workings.

To prevent collapse of workings passed through fractured rocks, anchor bolts with metal mesh and sprayed concrete are used. However, rocks exfoliation roof of transport drift and significant rocks destruction indicates that this support does not solve problem of ensuring stability of workings and does not prevent the development of deformations. As a result, after 2–3 years of standing workings, lining is destroyed and a major overhaul is required.

Unsatisfactory condition of sides of open pits is due to the tendency of rocks to destruction, which is shown in Fig.1. In this regard, a new approach is needed to the development of methodological complexes to increase stability of pit walls and ways to increase slope stability of ledges by strengthening and strengthening them (Bek et al., 2022: 8).

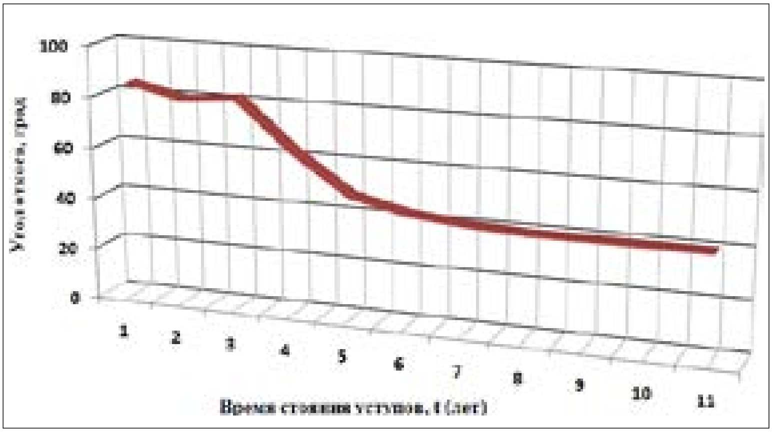

Fig.1 - Dependence of inclination angle of ledge on the standing time of ledges

The most well-known methods of strengthening fractured rocks in the massif include use of grouting. Cement mortar is prepared on basis of cement and water. This method of ensuring slopes stability and ledges of open pits is complex task, solution of which should include not only parameters determination of stable slopes, but also their management in order to achieve better economic results and natural resources. Here main challenge is to develop hardening solutions at low cost, with high strength.

To achieve this result, raw materials were studied: Portland cement PC 400-D0 (M400) produced by JSC Central Asia Cement (Karaganda region, Kazakhstan), tailings from the Akzhal processing plant, functional additive "Reparatur" produced by the company "Ading" (Northern Macedonia) and polycarboxylate additive "Neolit 400" (Russia).

Rationale for the choice of starting materials

Use of Portland cement PC 400-D0 is due to the location of the plant for its production in the vicinity of the city of Balkhash, not far from the Akzhal mine. Tailings choice of the Akzhal enrichment plant was carried out in order to improve ecological situation in the region's environment through their complete utilization with environmental and economic efficiency and use of carbonate composition of tailings to develop special cementing solutions for more effective hardening of rock fractures in underground workings with them.

In this regard, main characteristics of waste from the Akzhal concentrating plant were studied, the X-ray pattern and diffraction characteristics of which are shown in Fig. 2, from which it can be seen that they consist of calcite, therefore, reflections (peaks) characteristic of $CaCO_3$ are recorded on the X-ray pattern, 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.

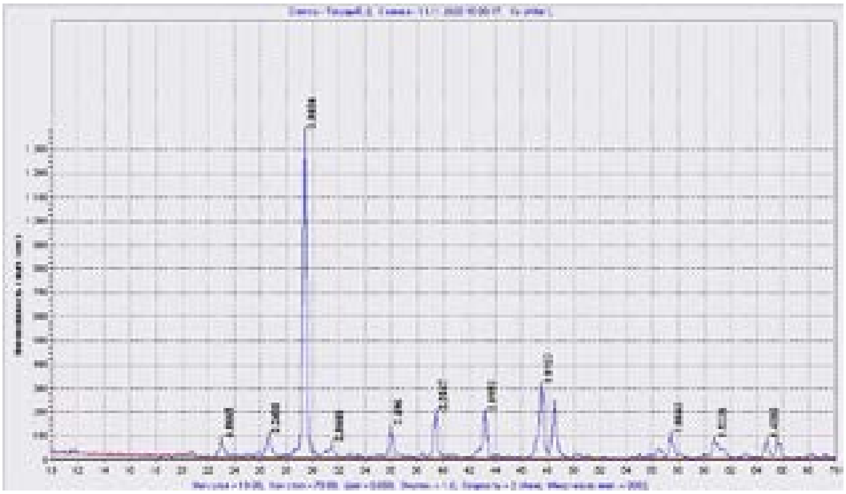

Fig. 2-X-ray of Akzhal mine tailings

Chemical analysis showed that the waste rock mainly consists of, %: CaO – 54.6; CO_2 – 39.4; SO_3 – 2.0; MgO – 1.5; SiO_2 – 2.5 %; Fe[S_2] – about 0.18. Based on the results obtained, it can be stated that the non-metallic rock of the Akzhal deposit consists of limestone ($CaCO_3$) – about 95 ... 97 % and silica (SiO_2) – about 2.5 ... 3 %.

Thus, analysis of mineral and chemical composition of non-metallic rock of the Akzhal lead-zinc deposit shows that it mainly consists of calcite – $CaCO_3$ (about 95 ... 97 %) and silica – SiO_2 (about 2.5 %); among them there are also impurity elements of magnesium, iron, aluminum, zinc, lead, barium, etc., which are not of industrial interest, since their total content does not exceed 1 %. The ore enrichment tailings of the Akzhal PF mainly consist of calcite and silica, the oxide chemical composition of which is represented by the following individuals: CaO – 54.3; CO_2 – 40.5; SO_3 – 2.3; SiO_2 – 1.5; MgO – 1.4 and Fe[S_2] – 0.13 %.

Mine and waste process water, respectively, have following characteristics: alkalinity – 0.45 and 0.8; hardness – 11 and 12; pH – 7.5 and 8.3. Moreover, mine is transparent, and technological one is muddy, which includes ore dressing tailings, consisting mainly of calcite - $CaCO_3$.

Discussion

The most promising areas of application of enrichment tailings are:

receiving on their basis without additional processing of plaster and mortgage mixes;

obtaining from them after firing at 1000°C lime used in various sectors of the construction industry;

Obtaining filler for asphalt-concrete-bitumen mixture.

The composition of plaster and mortgage mortars based on enrichment tailings show that:

solutions M 25...M 200 (~B2...B15) are light (1371...1449 kg/m3);

with increase in grade (class / solution), the content of cement and water in it increases, and the consumption of tailings decreases.

It should be noted that by injection chemical additives, including superplasticizers, it is possible to significantly improve physico-mechanical and technological properties of solutions, which requires additional research.

From non-metallic rock you can get:

crushed stone used as a coarse aggregate for concrete grades up to 300;

crushed stone used as an underlying layer for the base in the construction of highways;

filler as a mineral additive in the preparation of bitumen mix.

Use of mine water and waste process water released during ore dressing. The suitability of mine and process water was tested in accordance with the technical requirements of GOST 31108–2016. At the same time, these waters were used as a water filler for the cement-sand mixture. As a standard, a mortar mixture mixed with ordinary water was taken, the results of which show that:

setting of cement paste on technogenic waters occurs faster (160 and 170 min) than on ordinary water (180 min), which is positive effect;

water demand of cement paste on technogenic waters is somewhat higher (29.5 % and 31.0 %) than on ordinary water (29.0 %);

The rate of strength gain of cement stone, regardless of type of water mixing, is identical, however, strength of cement stone on process water is greater (44,4 MPa) than on ordinary and mine water.

It follows from foregoing that mine and process water may well replace ordinary water as thickener for mortar and concrete mixtures.

Based on the results obtained, we have proposed a solution for strengthening fractured rocks containing filler, cement and process water. To reduce cost of solution as a filler, it was proposed to use tailings of concentrating plants, which are a large-tonnage production waste and large areas are allocated for their storage (Bek et al., 2022: 5).

The most well-known methods of strengthening fractured rocks of massif include use of grouting. Here main challenge is to develop hardening solutions at low cost, with high strength. To achieve goal, solution is proposed for strengthening fractured rocks, containing filler, cement and water.

Additionally, a dry superplasticizer Neolit 400, which is produced by Neochim (Russia), has a high water-reducing ability and makes it possible to reduce the water-binding ratio in systems by more than 20%. With a decrease in the water-binding ratio, the durability and density of the developed mortar increase, with a simultaneous decrease in shrinkage and creep deformations during the curing of mortars. The additive is well compatible with Portland cements, cement – up to 37 %, tailings of processing plants – up to 52 %, Superplasticizer Neolit 400–0.11–0.16 and the rest is water.

Shown ratio of components was obtained experimentally in laboratory conditions. To find the strength of the mixture, samples of 4x4x16 cm are molded and compacted on a vibrating platform for 45 seconds, after a day they are removed from the molds and stored under humidity conditions for 28 days (starting value), and then physical and mechanical tests are carried out, results of which are presented in table 1.

Table - Physical and mechanical properties of the solution

example	Solution composition, wt.%				indicators		
	Cement	Concentration tailings	Neolit 400	Waste water of EP	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

These studies confirmed that the proposed composition of the solution for strengthening the fractured rock mass should be in the following ratio, wt. %: cement 32–37, tailings of processing plants 47–52, superplasticizer Neolit 400–0.11–0.16, the rest is water.

All components are loaded into a concrete mixer and thoroughly mixed with the addition of process water EP. Thus, the use of the solution described above ensures the strengthening of the cracked sections of the boards and can significantly reduce the harmful effects of waste processing plants on the environment.

The technical novelty of created solution was confirmed by the patents of the Republic of Kazakhstan for invention (Utility Model Patent, 2016).

Thus, use of solution described above ensures strengthening of weak sections of boards and can significantly reduce harmful effects of waste processing plants on the environment.

Conclusions

Thus, it can be argued that recycling of MMC waste into building materials is aimed at solving environmental and social problems in regions with developed mining and metallurgical industry. Rational organization of waste processing process, combined with efficient modern equipment, makes it possible to obtain products from secondary raw materials with a cost 2–2.5 times lower than for similar products from primary raw materials, with a comparable product quality. Economic efficiency of use of waste is determined by fact that technogenic raw materials have already been extracted from subsoil crushed to finely dispersed state and laid in dumps.

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