3. Shumskaya E. N., Sizykh A. S. Increasing of gold extraction from polymetallic ore of Novoshirokinskoe deposit. *Gornyi Zhurnal*. 2014. No. 11. pp. 44–48.
4. Nurpeisova M. B., Bitimbayev M. Zh., Rysbekov K. B. et al. Geodetic substantiation of the Saryarka copper ore region. *News of the National Academy of Sciences of the Republic of Kazakhstan-Series of Geology and Technical Sciences*. 2020. Vol. 6. pp. 194–202.
6. Yevdokimov S. I., Datsiev M. S., Podkovyrov I. Yu. Gravity separation in the conditions of specially formed high content metal in initial feed. *Izvestiya. Non-Ferrous Metallurgy*. 2014. No. 2. pp. 3–9.
7. Fullam M., Watson B., Laplante A., Gray S. Advances in gravity gold technology. *Gold Ore Processing (Second Edition)*. 2016. pp. 301–314. DOI: 10.1016/B978-0-444-63658-4.00019-0
8. Laplante A., Gray S. Advances in gravity gold technology. *Developments in Mineral Processing*. Elsevier. 2005. Vol. 15. pp. 280–307.
9. Koppalkar S., Bouajila A., Gagnon C., Noel G. Understanding the discrepancy between prediction and plant GRG recovery for improving the gold gravity performance. *Minerals Engineering*. 2011. Vol. 24, Iss. 6. pp. 559–564.
10. Bazaluk O., Rysbekov K., Nurpeissova M. et al. Integrated monitoring for the rock mass state during large-scale subsoil development. *Frontiers in Environmental Science*. 2022. Vol. 10. ID 852591.
11. Laplante A., Dunne R. C. The Gravity recoverable gold test and flash flotation. *Proceeding 34th Annual Meeting of the Canadian Mineral Processors. Ottawa, Canada*. 2002.
12. Nurpeisova M. B., Abenov A. M., Miletenko N. A., Dosetova G. Zh. Highly efficient monitoring procedure for deformation prediction in copper ore mining. *Eurasian Mining*. 2023. No. 1. pp. 19–24
13. Clarke J. A simplified gravity-recoverable-gold test. *ProQuest*, 2007.
14. Surimbayev B. N., Kanaly E. S., Bolotova L. S., Shalgymbayev S. T. Assessment of gravity dressability of gold ore — GRG-test. *Mining Science and Technology (Russia)*. 2020. Vol. 5, No. 2. pp. 92–103.
15. Peregudov V. V., Shautenov M. R., Ozhogin G. A., Motovilov I. Yu. Vibratory centrifugal bow-type batch-action apparatus. Patent RK. No. 30418. Published: 15.10.2015. EM

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THE USE OF MINING AND METALLURGY WASTE IN MANUFACTURE OF BUILDING MATERIALS

This article describes R&D connected with the technology of production of building materials using waste of the mining and metallurgical industry.

The subject of research are mill tailings, as well as backfill and reinforcement mixtures with and without addition of tailings. The object of research are physical and mechanical properties, and features of curing of the test mixtures in the conditions of natural humidity.

The characteristics of the initial materials, compositions of backfill and reinforcement mixtures, and their physical and mechanical properties were determined using standard techniques, and the physicochemical properties were identified from the X-ray diffraction analysis and infrared spectroscopy. Phases were specified on diffraction device DRON-3M, and the chemical analysis used X-ray fluorescent spectrometer EDX-8000. The granulometry was determined using three methods: sieve analysis by multifrequency screener MSA W/D-200 Kroosh Technologies Ltd.; diffraction analysis by laser particle size analyzer Helos-KR with Quixel add-on; dispersion analysis by a dry powder dispersion unit.

Toward the industrial and ecological safety, the qualitative and quantitative characteristics of waste from some large mines in Kazakhstan are described, and the environmental damage of the mining industry waste is investigated and taken into account. Mill tailings of a processing plant of a mining company in the Republic of Kazakhstan are analyzed. Some technologies are proposed to manufacture dry building mixtures and aerated concrete using mineral processing waste. The use of manmade mineral feedstock in manufacture of dry building mixtures and aerated concrete allows total substitution of carbonate and silica components, and saves consumption of Portland cement. The technical and economic effect of application of the developed compositions as masonry, finishing and polymeric materials for the building industry of Kazakhstan totals 329–2700 Tenge/m^3 of mixture. The technology of no cement porous concrete manufacture uses a binder represented by burnt and ground lime from furnacing of carbonate-bearing waste. The binder is used jointly with a silica component – tailings of rare metal and complex ore processing, containing silicon dioxide. The technology of manufacture of aerated concrete using tailings is aimed at achieving: required thermal–insulating properties at the average dry density not higher than 500 kg/m^3, structural–thermal–insulating properties at the average dry density of 500–900 kg/m^3 and structural properties at the average dry density of 900–1200 kg/m^3.

Keywords: *mining and metallurgy waste, ecological risks, mineral mining, open pit, underground mine, concentration plant, jointing, fractures, rock falls, reinforcement, mining waste, building materials*
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Introduction

The sector of mining and metallurgy in the Republic of Kazakhstan has accumulated a massive amount of overburden, mill tailings and slag for the long years of operation. The greater percentage of waste is the waste of nonferrous metal mining and metallurgy, with the biggest volume of rejects concentrated in tailings ponds (**Table 1**). The tailings represent a fine material that needs no additional milling before utilization, which allows reduction in economic costs. For another thing, processing of such material ensures its chemical and mineralogical uniformity.

Operating mines emit millions of tons of toxic substances in the atmosphere and discharge hundreds of millions of cubic meters of contaminated effluents in water basin. This entails severe economic, social and ecological consequences. By present-day estimates, Kazakhstan's mining sector has accumulated over 50 Bt of waste which occupies vast overall area (more than 150 km^2). Amount of industrial waste grows annually by 1.5 Bt while the use of solid mining waste is currently at a rather low scale [1].

Table 1. Manmade waste at large mining and processing plants

Mining and processing company	Waste, kt	
	Overburden dumps	Tailings ponds
Achpolimetal JSC	–	142 570.1
Belaya Gora GOK	24 406.0	10 067.8
Donskoi GOK	81 447.7	38 280.4
Kazakhmys	973 114.7	1 674 691.5
Zhairem GOK	6354.8	3188.8
Tekeli GOK	15 723.9	40 360.5
Kazzinc	–	373 147.1
Zhezdy GOK	89.7	3173.2
Kostanai Minerals JSC	–	2038.3

It is possible to increase supply of the building materials industry with mineral resources not only by finding new deposits of nonmetallics but also through introduction of nonmetallic waste into commercial production. Such manmade feedstock needs processing and appraisal using efficient methods and technologies toward its complete utilization at a high level of environmental protection.

Comparative analysis

The scaling construction in Kazakhstan requires much mineral raw materials to advance the industry of building materials. Progression is connected with substitution of primary natural resources for industrial waste with a view to making building materials cheaper. The use of solid mining waste in the industry of building materials is more cost-effective as compared with production of building materials on the basis of special-purpose mineral mining [2, 3].

a *b*

Fig. 1. Fracturing intensity measurement in rock mass

The review of the works of science in this research area shows that global practice has a large experience of using manmade mineral raw materials. For instance, in far-abroad countries, mining waste is used in manufacture of brick [4], concrete [5] and glass ceramics [6–8]. In Russia, building materials made of overburden rocks from the Tatarka rare metal deposit in the Krasnoyarsk Krai were used in manufacture of wet plaster mix for implementation of environmental measures, and concentrates were employed as an aggregate material for light concrete [9].

The same studies on using mining waste in production of building materials are performed in the Republic of Kazakhstan [10–12].

An additive agent made from complex ore milling tailings can improve properties of cement grout for reinforcement of jointed rock mass. It is found that backfill mixtures with the assigned high cohesive strength, manufactured from tailings, promote creation of wasteless mineral processing technologies, reduction of cost of products both in the mining industry and in the building material industry, as well as efficient nature management and environmental protection.

Smart organization of waste processing using up-to-date equipment allows production from second-hand materials at the cost 2–2.5 times lower than the same production from fresh raw materials at the comparable quality of final products.

The necessity of introducing tailings into commercial production has the following background:

— the life time of tailings ponds is limited, and many tailings ponds already are or nearly are filled to capacity;

— the tailings ponds occupying vast areas represent a finely dispersed and fugitive material and, consequently, are the source of elevated ecological risk for the regions in the influence zone of mineral mining and processing operations [13, 14].

The relevant and priority-oriented trend in mining and processing waste management is production of building materials. The review of previous research in this area exhibits ample theoretical studies on the use of manmade mineral materials. The analysis shows that manmade mineral raw stuff is commonly used in manufacture of building products.

Research methods

The characteristics of the initial materials and backfill mixtures, and their physical and mechanical properties were determined using standard techniques, while their physicochemical properties were disclosed using the X-ray diffraction analysis (XDA) and infrared spectrometry (IRS).

XDA used device DRON-3M (Russia), and X-ray crystallography was carried out on software-aided JCXA-733 Superprobe microanalyzer (Japan). The structure of waste was examined using polarizing microscope Leica ICH DM2500 (Switzerland) with a 100 W lighter which allows comfortable operation with differential interference contrast; the differential thermal analysis (DTA) was performed on derivative graphics device MOM-1500 D (Hungary); the chemical composition was determined on X-ray fluorescent spectrometer EDX-8000; the microhardness was measured using microhardness meter PMT-3 (Russia). The granulometry was determined using three methods: sieve analysis by multifrequency screener MSA W/D-200 Kroosh Technologies Ltd.; diffraction analysis by laser particle size analyzer Helos-KR with Quixel add-on; dispersion analysis by a dry powder dispersion unit.

Results and discussion

The Satbayev University is carrying out research on using mining waste with a view to producing:

- components for mixtures for reinforcement of damaged rocks in open pits and underground mines;
- components for gold-bearing binder;
- components for nonautoclave aerated concrete based on fly ash.

Reinforcement of jointed pit wall rock mass

Inspection of Akzhal pit wall, Nova-Zink showed that the highest amount of rock falls takes place in jointed rock mass and grows with longer life of the pit. Observations in Akzhal mine found out that roadways were stable within a month. In 2–3 months, fractures to 10–15 cm long appeared. Fracturing and rock falls developed for a half year, then dome-shaped roof collapse occurred, which greatly increased the scope and labor content of heading operations, and entailed a jump in the cost of maintenance and support of the damaged roadways.

The study of rock fracturing and development of fracture control techniques was performed as a case-study of the Akzhal deposit. According to the analysis of geological conditions and situations in roadways driven in damaged rocks, the highest effect on stability is exerted by steeply dipping fractures. The deposit is composed of hard rocks, and the enclosing rock mass is split by numerous differently oriented fractures and faults as a result of crustal folding process. Large tectonic faults and small fractures were identified. Intensity of fractures was determined from in-situ measurements using a surveying rod 1 m long or a ruler (**Fig. 1**).

Prevention of roof falls in roadways driven in jointed rock mass includes rock bolting in combination with wire mesh and shotcreting. However, exfoliation of roof rocks in a haulage drift and rock rupturing mean that this type of mine roof support is incapable to ensure stability and prevent deformations in roadway. As a consequence, after 2–3 years of service, mine roof support fails, and roadways need complete overhaul. Unsatisfactory condition of pit wall is governed by susceptibility of rocks to fracturing as illustrated in **Fig. 2**. In this connection, a new approach is required to elaborating guidelines on enhancement of pit wall slope stability by means of strengthening and reinforcement.

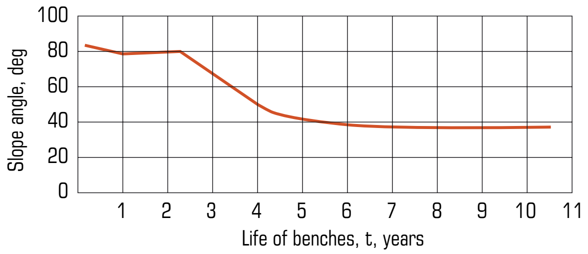

Fig. 2. Slope angle versus life time

Table 2. Physicomechanical properties of reinforcement solution

No.	Composition, mass%				Ultimate strength, MPa		Cone slump, mm
	cement	mill tailings	Neolit 400	water	compression	tension	
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	145
3	37	47	0.11	16.9	36.9	5.7	142

The test of the jointed rock samples displayed different levels of jointing in them. In open pit mining, it is important to have regard to life time of benches and slopes. Efficient and complete extraction of minerals using the open pit method requires that pit wall slope is surely stable. To this effect, the authors proposed a method of pit wall slope reinforcement.

One of the most common reinforcement methods is cement injection. Cementing in open pits starts from the upper bench site where rings of vertical and inclined holes are drilled. Then, cement mortar is injected in the holes until they are filled to capacity. The cement mortar is a mixture of cement and water. As a result, using the mining and metallurgy waste, the pit slope reinforcement is improved and reliable, and sloughing of the slope surface is prevented.

Such method of pit wall slope stability and reinforcement is an integrated problem including both determination of slope stability parameters and their control and adjustment toward the best economic efficiency and natural resource conservation. The main task is development of highly strong reinforcement mixtures at a low cost [15, 16].

In the proposed method, the inclined screen holes are drilled in parallel to a to-be slope surface and are blasted, and broken rock zones are created. Then, additional inclined holes are drilled. Rebars are placed in these holes and grouted. After that, holes are drilled at the bench site, bolts are placed in these holes, and cables are tensioned between the rebars and bolts.

The application of the method at operating open pits proved its reliability in pit wall slope reinforcement but displayed the method complexity.

Toward enhanced reinforcement of pit wall slopes, the broken rock zone is created by blasting the inclined screen holes drill in parallel to the to-be slope surface; after removal of blasted rocks and scraping of the slope surface, rebars with hooks are driven in the holes so that to adjoin the to-be slope surface. The hooks are used to fixate a wire mesh on the slope surface, and then a bracing solution is applied over the mesh. The bracing solution is made of the tailings from the local concentration plant.

The pit wall slope reinforcement chart is shown in **Fig. 3**.

Based on the implemented research, the authors proposed a bracing solution for jointed rock mass, containing an aggregate, cement and process water. For reducing the cost of the solution, in the capacity of the aggregate, it is suggested to use mill tailings representing heavy tons of waste stored over vast areas.

Dry highly water-reducing superplasticizer admixture Neolit 400, manufactured by Neochim, allows decreasing the water–binder ratio in the system more than by 20%. With the decrease in the water–binder ratio, the durability and density of the solution grow, while the shrinkage and creep deformation during development of strength diminish; moreover, the admixture is compatible with Portland cement. The ratio of the components in the solution to reinforce jointed rocks is as follows: cement — to 37%, mill tailings — to 52%, superplasticizer Neolit 400 — 0.11–0.16%, and the rest is water. The ratio was obtained experimentally during lab-scale tests. For the strength tests of the mixture, the samples 4×4×16 cm are manufactured and compacted on a platform vibrator for 45 s; the day after, the samples are removed from their mold boxes and held in a wet medium for 28 days (lower limit) before physicomechanical testing. The test results are given in **Table 2**.

Thus, the use of the proposed solution ensures reinforcement of weak pit wall slopes and greatly reduces environmental impact of mill tailings. The technical novelty of the solution is proved by patents of invention of the Republic of Kazakhstan (Patent No. 1573 Jointed Rock Reinforcement Compositions; Patent No. 36246 Pit Wall Slope Reinforcement Method) [16].

Effective reinforcement solution for jointed rocks in underground roadways

The analysis of geological conditions at the Akzhal deposit and situation in roadways driven in faulted rocks shows that fracturing has a high influence on the roadway stability. The strength of rocks drops on exposures and at contact with air and water, which necessitates a differential approach to ground control in rocks of different jointing degree. One of the most common methods is shotcrete reinforcement of damaged rock zones, i.e. injection of cement grout in rock mass until its full saturation [17].

For the jointed rock reinforcement in underground roadways, the authors proposed an effective composition of shotcrete. The technical result is utilization of mining waste and mill tailings, achievement of high flowability of the mixture, as well as high adhesion and strength of the resultant solution.

To that end, the following materials were tested: Portland cement PC 400, Central Asia Cement JSC, Karaganda Region, Kazakhstan; mill tailings of Akzhal concentration plant; functional additive Reparatur, Ading JSC,

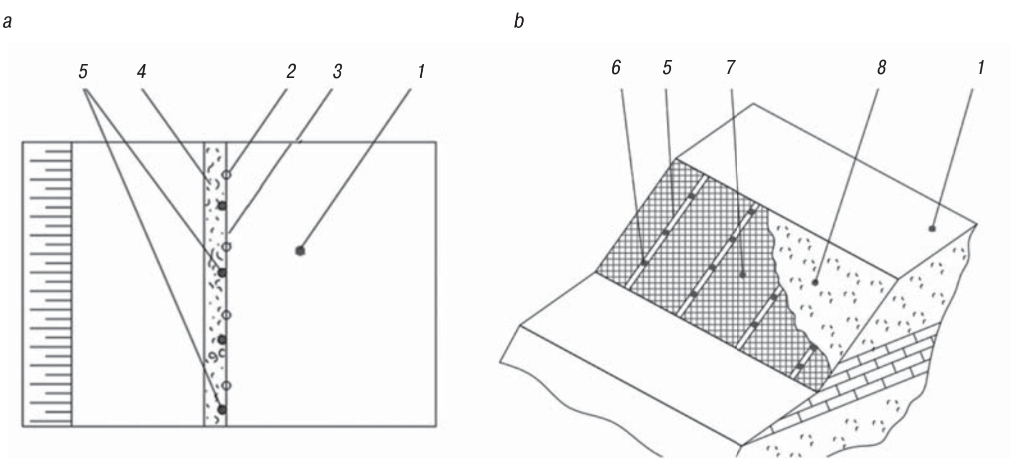

Fig. 3. Slope reinforcement chart: ***a*** **— plane view of working site;** ***b*** **— isometric view of slope**
1 – working site of open pit slope; *2* – inclined hole; *3* – slope surface; *4* – broken rock zone; *5* – rebars; *6* – hooks; *7* – wire mesh; *8* – bracing solution layer

North Macedonia; polycarboxylate superplasticizer Neolit 400, Russia.

Justification of the choice of the test materials:

1. Portland cement PC 400, Central Asia Cement JSC — is chosen owing to close-spaced location of the manufacturing plant at the city of Balkhash, not far from Akzhal mine;

2. Mill tailings of Akzhal concentration plant are selected because of:

— the requirement to improve ecological situation in the region by means of complete recycling of tailings at high ecological and economic effect;

— the carbonate composition of the tailings suitable for especially binding mixtures for more effective reinforcement of jointed rocks in underground roadways.

3. Dispersed polymeric powder — additive Reparatur, Ading JSC, North Macedonia — is chosen because of its properties, including the higher strength of adhesion to rock surface.

4. Dry superplasticizer Neolit 400, Russia — is selected owing to its high water-reducing properties. With the decrease in the water–binder ratio, the durability and density of the solution grow, while the shrinkage and creep deformation during development of strength diminish.

The X-ray patterns of Akzhal tailings show mostly peaks indicative of calcium carbonate ($CaCO_3$), with interplanar spacings d, 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. **Figure 4** depicts the DTA analysis with the recorded endo-effect at the temperature of 950 ºC, which is reflective of dissociation of limestone.

The analysis of the mineral and chemical composition of rock products from the Akzhal lead–zinc ore deposit shows that they mostly consist of calcite $CaCO_3$ (around 95...97%) and silica SiO_2 (around 2.5%); there are also admixtures of magnesium, iron, aluminum, zinc, lead, barium etc. which have no commercial value as their total content is less than 1%.

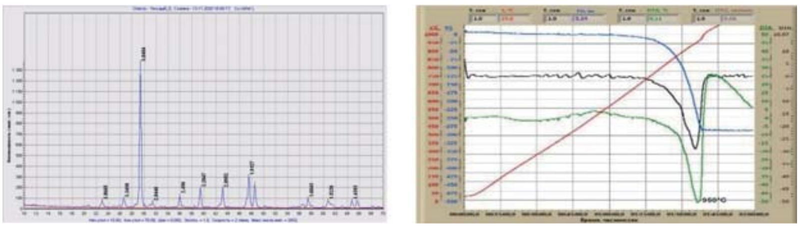

Fig. 4. X-ray pattern (*a*) and derivatography pattern (*b*) of Akzhal mill tailings

Table 3. Physicomechanical properties of reinforcement mixture

Composition, mass%					Characteristics	
Portland cement	Mill tailings	Reparatur	Neolit 400	Waste water	Compressive strength, MPa	Flowability, cm
18	71.2	1.5	0.3	9	21.5	100

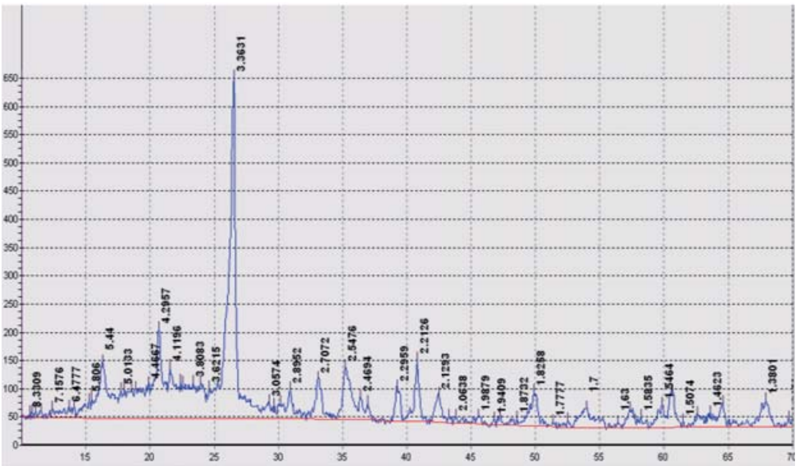

Fig. 5. X-ray pattern of TPP 3 ash [14]

Akzhal mill tailings mostly consist of calcite and silica, with their chemical compositions represented by: 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 waste and process water has the following characteristics: alkalinity — 0.45 and 0.8; hardness — 11 and 12; pH — 7.5 and 8.3, respectively. Mine water is clean, and process water is muddy as it contains tailings composed mostly of calcite $CaCO_3$.

The mix proportion for jointed rock reinforcement in underground roadways is selected: Portland cement PC 400 — to 18%, mill tailings — to 71.2%, additive Reparatur — 1.5%, superplasticizer Neolit 400 — 0.3%, water (water–cement ratio about 0.5) — 9%.

After proportioning of the components of cement, tailings and additive, the mixture is placed in a cement mixer and intermixed. Then water is added, and the mixture is intermixed again. The finished composition is delivered to underground roadways and injected in fractures.

For the strength testing of the composition, the samples 7×7×7 cm were manufactured and compacted on a platform vibrator for 45 s; the day after, the samples are removed from their mold boxes and held in a wet medium for 28 days (lower limit) before physicomechanical testing. The test results are given in **Table 3**.

The technical novelty of the produced solution was proved by a patent for invention of the Republic of Kazakhstan (Patent No. 36220 Reinforcement Composition for Jointed Rocks in Underground Roadways).

The shotcrete-based technology of jointed rock reinforcement was tested in underground roadways of the mines Akzhal and Saryoba. The analysis of the test results showed that the highest technological and economic figures of shotcrete reinforcement were achieved through the properly selected composition of concrete mixture, with regard to specific geological and hydrogeological conditions of underground roadways.

Ash and slag waste utilization in production of building materials

Power consumption in the world grows year by year, and thermal power plants buildup their capacities as a result. TPP generate electric power while combusting coal but also produce great amount of fly ash, bottom ash and boiler slag (hereinafter, ash and slag waste). By now ash and slag waste accumulated in the area of Kazakhstan reach more than 500 Mt and are still growing [3, 18, 19]. Piling and storage of ash and slag leads to a vast land loss in the world and causes adverse environmental pollution in adjacent areas. Currently, the Satbayev University is implementing R&D in the field of the ash and slag management technologies.

It is expedient to use TPP ash and slag waste as a production cycle by-product. The aim of the study is to analyze the physicochemical properties of ash and slag of Ekibastuz coal combustion, and to estimate the waste applicability in manufacture of demandable building materials at the reduced anthropogenic load intensity laid on the environment. To this effect, some objectives are set, namely:

— to determine mineral phases of ash;

— to determine chemical composition of ash;

— to determine grain size composition of ash;

— to perform compression and tension testing of ash samples.

The authors tested ash and slag waste of the Almaty TPP. The Almaty TPP integrates 3 heat and power plants (TPP 1, TPP 2 and TPP 3) which supply heat

Table 4. Steaming of test samples

Composition, mass%		Specific surface area, cm^2/g	Water–cement ratio	Cone flow, mm	Ultimate strength, MPa			
					after steaming		at the age of 28 days	
cement	ash				tensile	compressive	tensile	compressive
100*	–	289	0.45	110	4.8	26.2	5.3	44.3
70	30	550	0.33	112	7.8	55.5	8.9	75.8
50	50	570	0.35	112	6.7	50.3	8.3	70.3
30	70	580	0.37	112	5.8	40.3	7.9	65.5
Comment* — initial cement, without additional milling and superplasticizer								

and power to the consumers in the city of Almaty and in the Almaty Region in Kazakhstan. All TPP use coal from the Ekibastuz coal field. At the ash dump of TPP 3, common samples 3–5 to 15–16 kg in weight were taken and used later on to make group samples.

Figure 5 shows an X-ray pattern of TPP 3 ash. The interpretation of the X-pattern reveals the following minerals, % of crystal phase: hematite Fe_2O_3 — 12.1%, quartz SiO_2 — 32.4%, sillimanite Al_2SiO_5 — 25.9%, and mullite $Al_{4.95}Si_{1.05}O_{9.52}$ — 29.6%.

The chemical composition of the samples was as follows, %: SiO_2 — 57.7; Al_2O_3 — 29.6; (Fe_2O_3+ FeO) — 6.4; CaO — 1.1; MgO — 0.35; SO_3 — 1.3; K_2O — 0.03; Na_2O — 0.52; loss on ignition — 3.0.

One of the key characteristics of a raw material is the grain size composition. With higher micro-particle dispersion, i.e., with higher content of particles smaller than tenths-of-a-millimeter, plasticity of a material is better. Consequently, the material possesses high coherence, which is beneficial for the strength characteristics of an end product. High plasticity allows a material to change its shape without fracture and failure. This is important for the materials subjected to thermal treatment. Materials with high micro-particle dispersion are more elastic, flexible and suitable for molding, which ensures high quality of an end product [20].

It is promising to produce and use ash cement without mineral additives. It is possible to achieve the higher strength of an ash cement mixture by selecting a more effective method of intermixing. One of such methods is joint ball milling of ash and cement at a preset ratio and in the presence of dry superplasticizer S-3 in amount of 1.0…1.5% of cement weight. The feed material to produce high-strength ash cement are: Portland cement CEM 1 32.5, fly ash of Ekibastuz HPP 2 and dry superplasticizer S-3 manufactured by Poliplast company.

Predried cement and fly ash are placed in a bill mill. Milling duration is 6 h. After 3 h of milling, the required among of S-3 is added in the mill ball with cement and fly ash. After unloading, specific surface area is determined instrumentally.

From the resultant mixtures, samples 4×4×16 cm are manufactured and tested in accordance with state standard GOST 30744-2001 and with regard that the cement and ash mixture contains the superplasticizer. For this reason, the cone flow was maintained within a limit of 110–112 cm. The steaming mode of the sample was 2 + 10 + 2 h at the isothermal process heating of 95°C [21]. The results are compiled in **Table 4**. From the results of heating, the following conclusions are drawn:

As compared with initial cement (without additional milling), the compressive strength of the premilled cement and ash mixture is much higher and reaches 40.3…55.5 MPa (as against 26.2 MPa) after steaming and 65.5…75.8 MPa (as against 44.3 MPa) at the age of 28 days;

The same takes place in case of the tensile strength: 5.8…7.8 MPa (as against 4.8 MPa) after steaming and 7.9…8.9 MPa (as against 45.3 MPa) at the age of 28 days.

The observed effects can be explained as follows:

— high-rate milling makes particles of cement and fly ash partly amorphous, which improves their reactive capacity;

— superplasticizer S-3 particles adsorb at active surfaces and centers, which contributes to finer milling of cement and fly ash particles;

— hydration of the mixture enhances efficiency of S-3 even more, namely:

S-3 requires smaller amount of water owing to the plasticizing capacity of the agent, and flowabilty of the mixture grows;

C-3 dissociates floccules — aggregated grains of cement and fly ash, and entrapped water is liberated as a result, and participates in hydration;

in the curing hydration system of cement, fly ash, SP and water, the superplasticizer molecules detach ion of Na^+, and the rest anions consist of hydrocarbon radical and some hydrophilic groups of SO_3^-, distributed along the length of a molecule, and anions adsorb flat at the positive-charge particles of cement and fly ash and hydration products, and give them the negative charge, which enhances cohesion between the particles of new hydrated forms.

Testing

The next stage of the research involved manufacture of ceramic bricks with addition of ash and slag.

With that point in view, it was necessary to carry out a series of technological processes, including treatment of feedstock, molding of ceramic samples and their furnacing at a high temperature. After furnacing, mechanical and physical testing of the ceramic–ash–slag sample was undertaken. The test results allowed concluding that ash and slag addition influenced the properties of the ceramic bricks, namely, their strength and wear resistance.

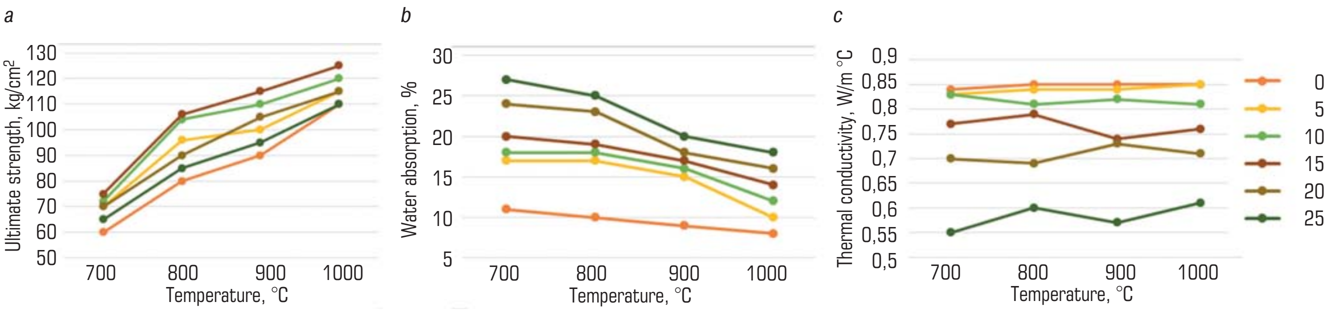

Fig. 6. Relationship between furnacing temperature and:
a – ultimate strength (ash content in clay 0–25); *b* – water absorption (ash content in clay 0–25); *c* – thermal conductivity (ash content in clay 0–25) [14]

In this study, it was selected to manufacture ceramic bricks by the lab-scale method of plastic molding, with different percentage of ash and slag, and with furnacing at different temperatures (Patent No. 8979 Ash-Bearing Binder Production Method; Patent No. 8980 Production Method and Composition of Nonautoclave Aerated Concrete Based on Fly Ash). **Figure 6** illustrates the relationship between the furnacing temperature, the sample properties and the ash content in clay.

The analysis of the test data of Ekibastuz coal combustion ash and slag shows that the thermal conductivity and water absorption of the sample depend on the ash content and furnacing temperature. With the higher ash content, the thermal conductivity of the test brick is lower. The water absorption increases with the increasing ash content. The compressive strength lowers with the increasing ash content of bricks. Thermal conductivity of ceramic bricks is one of the key parameters influenced by the ash content. With the higher ash content, the thermal conductivity is lower. The optimal percentage of ash and slag waste to be added in a ceramic brick is 15% at the furnacing temperature of 1000°C.

Based on the research findings, the authors think the further research should be aimed at optimization of processes in production of building materials using ash and slag waste.

Conclusions

1. The use of manmade mineral materials as additives or components in manufacture of building materials promotes creation of low-waste and wasteless technologies of mineral processing, contributes to effective utilization of mineral resources and provides solutions to some ecological issues of bio-geo-ecotope — ecosystem.

2. The implemented studies show that manmade mineral-bearing materials accumulated at concentration plants (Akzhal, Zhezkazgan) are effective components of building materials. The reinforcement solutions for jointed rock mass, created and introduced in the industry, use mining and processing waste and polymeric powders which feature a low cost, a sufficient flowability to fill even fine fractures, and a high strength. Addition of tailings in amount of more than 50% reduces the mixture flowability and adhesion to rocks, while addition of tailings in amount less than 45% raises the cost of the end solution.

3. The physicochemical properties of Ekibastuz coal combustion ash sampled from ash dumps of Almaty TPP 3 are tested. The results prove the usability of ash and slag waste as a secondary raw material with a view to reducing the anthropogenic load intensity laid on the environment.

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References

1. Information on organization of waste management in regions of the Republic of Kazakhstan. Astana, 2018. 2019. Available at: http://ecogosfond.kz/wp-content/uploads/2019/11/Informacionnyj-obzor-po-vedeniju-gosudarstvennogo-kadastra-othodov-za-2018_compressed.pdf (accessed: 11.04.2024).
2. Lewińska P., Dyczko A. Thermal digital terrain model of a coal spoil tip — A way of improving monitoring and early diagnostics of potential spontaneous combustion areas. *Journal of Ecological Engineering*. 2016. Vol. 17, Iss. 4. pp. 170–179.
3. Wang J., Apel D. B., Dyczko A., Walentek A., Prusek S. et al. Analysis of the damage mechanism of strainbursts by a global–local modeling approach. *Journal of Rock Mechanics and Geotechnical Engineering*. 2022. Vol. 14, Iss. 6. pp. 1671–1696.
4. Zhang L. Production of bricks from waste materials — A review. *Construction and Building Materials*. 2013. Vol. 47. pp. 643–655.
5. Salguero E., Grande J. A., Vabnte T. et al. Recycling of manganese gangue materials from waste-dumps in the Iberian Pyrite Belt — Application as filler for concrete production. *Construction and Building Materials*. 2014. Vol. 54. pp. 363–368.
6. Melkonyan R. G. Environmental problems of waste disposal mining for glass and construction industry. *Journal of Science and Education of North-West Russia*. 2017. Vol. 3, No. 1. pp. 58–69.
7. Baibatsha A., Omarova G., Dyussembayeva K. Sh., Kassenova A. T. Kokkiya — A promising for Kazakhstan gold-metasomatic type of deposit. *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM*. 2016. Vol. 1. pp. 289–296.
8. Jiang Shi., Feng He., Chuqiao Ye. et al. Preparation and characterization of CaO-AlO-SiO_2 glass-ceramics from molybdenum tailings. *Materials Chemistry and Physics*. 2017. Vol. 197. pp. 57–64.
9. Lygina T. Z., Luzin V. P., Kornilov A. V. Multi-purpose use of technogenic non-metallic raw materials and obtaining new types of products from them. *Theoretical Framework and Practice of Ore and Manmade Waste Processing — XXII International Conference Proceedings*. 2017. Vol. 1. pp. 67–71.
10. Baidjanov D. O., Rahimov M. A., Rahimov A. M. Technology for producing foam glass-crystalline heat-insulating materials based on industrial waste. *Trudy universiteta*. 2017. No. 4(69). pp. 73–76.
11. Utegulov B., Utegulov A., Begentayev M., Uakhitova A., Zhakipov N. et al. Method for determining the insulation in asymmetric networks with voltage up to 1000 V in mining enterprises. *Proceedings of the IASTED International Conference on Power and Energy Systems and Applications, PESA 2011*. 2011. pp. 54–57
12. Kenzhina I. E., Kozlovskiy A. L., Chikhray Y. et al. Study of Gas Swelling Processes under Irradiation with Protons and He^{2+} Ions in Li_4SiO_4–Li_2TiO_3 Ceramics. *Crystals*. 2023. Vol. 13, Iss. 10. ID 1526.
13. Zikirina A. M., Temirtassova A., Kozlovskiy A. L., Kenzhina I. E., Begentayev M. M. Synthesis, characterization and evaluation of the application of cozn nanostructures as anode materials. *Batteries*. 2023. Vol. 9, Iss. 8. ID 421.
14. Nurpeisova M., Estemesov Z., Gabbasov S., Ashimova A., Bek A. Studying the properties of ash and slag waste for use in the manufacture of construction products. *Mining of Mineral Deposits*. 2023. Vol. 17, Iss. 3. pp. 102–109.
15. Sultanbekov T. K., Shayahmetov G. Z., Dauletov N. D., Estemesov Z. A. Dry building mixture mini-plant. *Cement and Its Applications*. 2000. No. 3. pp. 38-40.
16. Bek A. A. Pit wall slope reinforcement method. Certificate of the Republic of Kazakhstan of inclusion of data in the state register of rights for objects (art of science), No. 31344. 22.12.2022.
17. Bek A. A., Yestemesov Z. A., Baidzhanov D. O., Fedotenko N. A. Effective strengthening solutions for fractured rock masses using tailings. *Eurasian Mining*. 2022. No. 1. pp. 59–63.
18. Kuldeyev E., Seitzhanova M, Tanirbergenova S., Tazhu, K., Doszhanov E. et al. Modifying natural zeolites to improve heavy metal adsorption. *Water*. 2023. Vol. 15, Iss. 12. ID 2215.
19. Nurpeisova M. B., Yestemesov Z. A., Lozinsky V. G., Ashimova A. A. et al. Industrial waste recycling — one of the key directions of business development. *News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences*. 2023. Vol. 3, No. 459. pp. 193–205.
20. Nurpeisova M. B., Estemesov Z. A., Fedotenko N. A., Gabbasov S. G Technology of utilization and use of ash and slag waste to ensure environmental safety at the region. *Sustainable Development of Mountain Territories*. 2023. Vol. 15, No. 3(57). pp. 631–639.
21. Kuldeyev E. I., Nurpeisova M. B., Fedorov E. V., Ashimova A. A. Study of aggloporite producibility from the Ekibaztuz coal ashes. *Eurasian Mining*. 2023. No. 2. pp. 85–88. EM