НАУЧНАЯ СТАТЬЯ
УДК 662.673.13
https://doi.org/10.56195/20793332-2026-26-4-66-70

SCIENTIFIC ARTICLE
UDC 662.673.13

Study of the application of ash and slag waste in building materials production technology

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Abstract. The article presents the results of an assessment of the impact of ash dumps on the natural environment in the conditions of coal burning at the Ekibastuz deposit in Kazakhstan. It is shown that huge amounts of ash dumps have accumulated on the territory of the Ekibastuz GRES-2 ash storage facility and in the Almaty region as a result of the activities of three thermal power plants, which significantly pollute the environment. The possibilities of obtaining high-demand building materials from them have been identified.

Keywords: ash and slag waste, analysis, pollution, ecology, secondary resources, building materials

Acknowledgment, funding. This research was carried out within the framework of grant funding from the Ministry of Science and Higher Education of the Republic of Kazakhstan BR21882292.

For citation: Begentayev M., Kuldeev Ye., Nurpeisova M.B., Bekbassarov Sh., Bek A.A., Study of the application of ash and slag waste in building materials production technology. *Mine Surveying and Subsurface Use.* 2026; 26 (4): 66-70. https://doi.org/10.56195/20793332-2026-26-4-66-70.

Исследование золошлаковых отходов в технологии производства строительных материалов

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Резюме. В статье приведены результаты оценки влияния золоотвалов на природную среду в условиях сжигания углей Экибастузского месторождения Казахстана. Показано, что на территории золохранилища Экибастузской ГРЭС-2 и в Алматинской области в результате деятельности трех тепловых электроценталей накопились огромные количества золоотвалов, существенно загрязняющих окружающую среду. Определены возможности получения из них востребованных строительных материалов.

Ключевые слова: золошлаковые отходы, анализ, загрязнение, экология, вторичные ресурсы, строительные материалы

Благодарность, финансирование. Данное исследование выполнено в рамках грантового финансирования Министерства науки и высшего образования Республики Казахстан BR21882292.

Для цитирования: Бегентаев М., Кулдеев Е., Нурпеисова М.Б., Бекбассаров Ш.Б., Бек А.А. Исследование золошлаковых отходов в технологии производства строительных материалов. *Маркшейдерия и недропользования*. 2026; 26 (4): 66-70. (In Russ.). https://doi.org/10.56195/20793332-2026-26-4-66-70.

Introduction

Kazakhstan has a significant number of thermal power plants. Every year, the amount of ash and slag waste (ASW) generated at combined heat and power plants (CHPs), state district power plants (SDPPs), as well as in boiler houses increases. The fuel and electricity complex is one of the main "pollutants" of the natural environment [1-3]. By burning coal, enterprises obtain thermal energy and generate electrical energy. Negative side of this process is formation of by-products of coal combustion - fly ash and slag.

It is known that storing ash and slag waste is a very expensive undertaking. According to expert estimates, investments in the reconstruction of one ash and slag dump can reach 5 billion tenge, and construction of a new one costs 10-12 billion tenge. Storage of ash and slag waste not only leads to the withdrawal of significant land areas, but also causes very significant environmental pollution [4, 5].

Deterioration of ecological situation is reasonably linked to atmospheric pollution. Long-term storage of thermal energy waste in ash dumps contributes to harmful substances and heavy metal ions entering the water and soil. The anthropogenic component of formation of water surface quality is already commensurate with the natural component, which poses a threat to sustainable water use. The annual yield of ash, ash and slag mixtures from coal combustion in ash dumps in Kazakhstan is more than 17 million tons. Over 300 million tons of ash wastes have been accumulated in ash dumps [6, 7].

Electricity production development and recycling of TPP waste, in particular, ash from coal combustion, is one of the main state priorities of Kazakhstan. Figure 1 shows volumes of ash and slag waste generation by Kazakhstan regions in 2025 [8, 9].

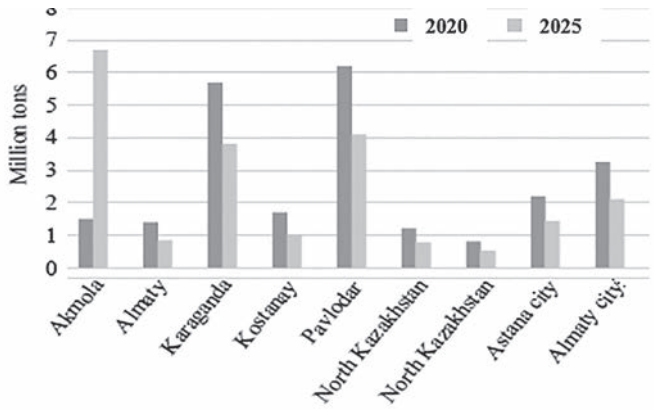


Fig. 1. **Formation of ash and slag waste in the regions of the Republic of Kazakhstan**

Remaining regions of Kazakhstan use gas fuel. In Kazakhstan, about 8% of ash (less than 1.9 million tons) from coal ash and slag waste produced by thermal power plants and state district power plants is processed at the research and production level. If the ASW use remains at this level, then by 2030 volume of accumulated waste will reach 1 billion tons [10, 11].

One of the largest thermal power plants in Kazakhstan is Almaty Electric Station CHPP-3 JSC, which provides energy to about 70% of consumers in the Almaty region. Waste from CHPP-3 is not processed, and current ash waste accumulates and occupies huge areas, which removes it from land use. Storage of ash and slag waste not only leads to withdrawal of significant land areas, but also causes very significant pollution of almost all environmental components in the area where they are located.

The purpose of this work is to study the properties of ash and slag waste from coal burning at the Ekibastuz deposit in Kazakhstan, evaluate them as a source of contamination of the natural environment and determine the possibility of obtaining demanded building materials from them.

Methods and object of research

To determine the phase composition of the studied material, an upgraded DRON-3M diffractometer based on CuKa radiation with software was used. X-ray images of the sample were obtained in the range of 2 ° (angles) from 10 to 70°. The chemical composition was determined using an EDX-8000 energy dispersion spectrometer. A micrograph of fly ash was taken using a Superprob-733 scanning electron microscope.

The object of the study is the elemental composition of ash and slag waste from CHP-2.

At the TPP-2 ash dump, ordinary samples weighing from 3-5 to 15-16 kg were taken, of which group samples were subsequently compiled [12].

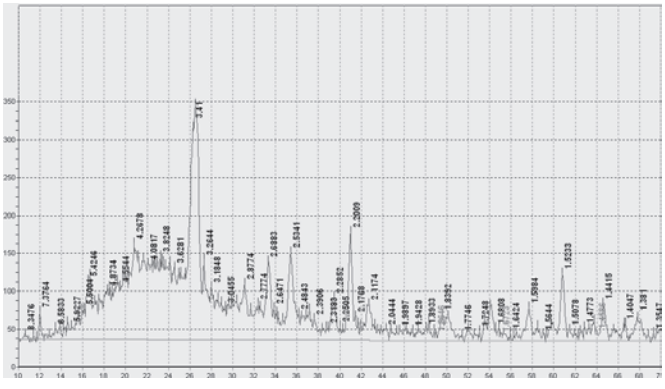
The results of the study and their discussion

Primary laboratory tests

Intensification in this direction involves the use of industrial waste instead of primary natural resources in order to reduce the cost of building materials. In this area, scientists at Satbayev University are conducting a large amount of research on the production of secondary raw materials based on industrial waste [13]. By burning coal, thermal power plants receive thermal energy and generate electrical energy. The negative side of this process is the formation of byproducts of coal combustion – fly ash and slag. The composition of the ash and slag material was determined by the quantitative ratio of the minerals included in it, which depend on the mineralogical composition of the initial part of the fuel. An X-ray diffractometer DRON-3 was used to obtain an X-ray image of the TPP-2 ash, which is shown in Figure 2.

The fly ash has the following chemical composition, %: 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; LOI – 3.0. Only the glassy phase containing microspheres exhibits pozzolanic and hydraulic activity; mullite ($3Al_2O_3 \cdot 2SiO_2$), quartz (SiO_2), sillimanite (Al_2O_3), hematite (Fe_2O_3), and carbon (C) are inactive. Trace elements (P, Sc, Mn, Pb, Ti, As, Zr, Ge, Ga, W, Ni, Cr) are incorporated into minerals and the glassy phase. Specific surface area – 290 m²/kg; true density – 2.1 g/cm³; bulk density – 780 kg/m³. Microphotograph (Fig.2, b) shows spherical vitreous hollow particles ranging from 1 to 50 μm, with larger spheres containing smaller inclusions and adhered fine satellites.

a)



b)

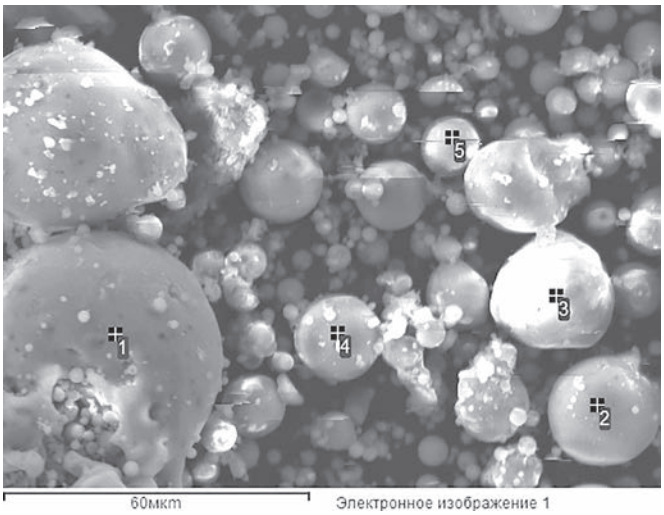


Fig. 2. **X-ray diffraction pattern (a) and microphotograph (b) of fly ash**

Research and production of secondary raw materials

One of the most promising areas is the involvement of industrial waste, in particular the ash of thermal power plants, in the composition of building materials. This approach allows us to simultaneously solve three key tasks: economic, technological and environmental. From an economic point of view, the use of ash provides a significant reduction in costs by replacing some of the cement and natural aggregates, which is especially important in the context of rising prices for raw materials. On the technological side, ash acts as an active mineral component that improves the physical and mechanical properties of building materials, increasing their strength, durability and resistance to environmental influences. The environmental aspect is expressed in reducing the volume of waste to be disposed of in landfills, which reduces the anthropogenic load and promotes the transition to the principles of "Green Kazakhstan" [14].

Within the framework of the state-supported Program-Targeted Financing (PTF) program, Politech Construction LLP was established at Satbayev University to implement innovative technologies for recycling ash-containing waste into construction materials. The company is currently engaged in processing ash accumulated at the ash disposal sites of Almaty CHPP-2 and CHPP-3, transforming it into valuable secondary raw materials for the production of advanced construction materials [15]. As a result of the conducted research and development, the following outcomes were achieve:

– a method has been developed for producing an ash-containing binder, the technical novelty of which is confirmed by a patent of the Republic of Kazakhstan[1];

– a method has been developed for producing non-autoclaved reinforced concrete from the ashes of Ekibastuzskaya GRES-2, the technical novelty of which is confirmed by a patent of the Republic of Kazakhstan[2];

– a method has been developed for producing agoporite, a filler for light concrete from the ashes of Ekibastuz coal. The technical novelty of the obtained agglomeration aggregate for light concrete is confirmed by the author's certificate[3];

– a composition and preparation method for geopolymer ash concrete were developed[4];

– a composition and preparation method for self-compacting ash concrete were developed[5];

– a raw material mixture for splitter ash blocks and a method for its preparation were developed[6];

– a composition and preparation method for ash fiber-cement facade panels were developed[7].

Based on the results of scientific research, a technology for the production of ash and slag-containing building materials has been developed (Fig. 3).

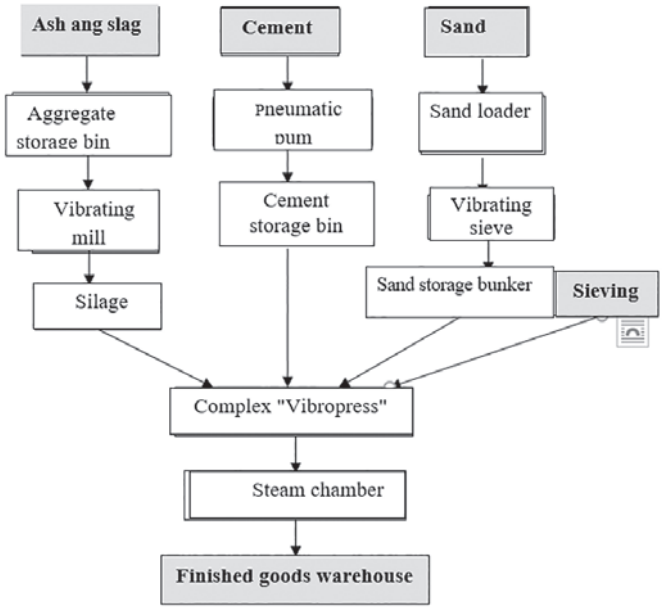


Fig. 3. **Technological scheme of production of ash and slag materials**

The introduction of ash and slag waste makes it possible to significantly change the cost structure. In the traditional production cycle, cement accounts for up to 45-50% of costs.

[1] Patent № 8579 of the Republic of Kazakhstan "Method for producing ash-containing binder" (authors: Kuldeev E.I., Nurpeisova M.B., Estemesov Z.A., Lozinsky V.G., Bek A.A., Ashimova A.A.). dated October 27, 2023.

[2] Patent № 8580 of the Republic of Kazakhstan "Composition and method of producing ash and gas concrete of non-autoclave hardening (authors: Kuldeev E.I., Nurpeisova M.B., Estemesov Z.A., Lozinsky V.G., Bek A.A., Ashimova A.A) dated on October 27, 2023.

[3] Author's certificate No. 44179 RK for a work of science dated 02.02.2024. Method for obtaining agloporite - filler for lightweight concrete from ash dumps of the city of Almaty. (authors: Nurpeisova M.B., Begentaev M.M., Kuldeev E.I., Nurlybaev R.E., Orynbekov E.S.)

[4] Patent № 37695 of the Republic of Kazakhstan «Composition and method of preparation of geopolymer gold concrete» (Authors: Nurpeissova M., Kuldeev Ye., Nurlybayev R., Orynbekov Ye., Bek A.). dated 19.12.2025.

[5] Patent № 37888 of the Republic of Kazakhstan "Composition and method of preparation of self-compacting gold concrete" (Authors: Nurpeissova M., Begentayev M., Kuldeev Ye., Bek A.). от 19.12.2025. dated 13.03.2026.

[6] Patent № 37063 of the Republic of Kazakhstan "Raw mixture for splitter ash block and method of preparing the mixture" (Authors: Nurpeissova M., Begentayev M., Kuldeev Ye., Nurlybayev R., Orynbekov Ye., Bek A.). dated 29.05.2026.

[7] Patent № 38127 of the Republic of Kazakhstan "Composition and method of preparation of ash fiber cement panels for facades" (Authors: Nurpeissova M., Begentayev M., Nurlybayev R., Bek A.). dated 10.07.2026.

Fig. 4. **Mobile workshop for the production of ash and slag products of Politech Construction LLP and finished products**

Its partial replacement with ash in the range of 15-20% provides savings of about 20-25 tenge per unit of production. In addition, the use of ash and slag components instead of some natural aggregates (sand and crushed stone) reduces the cost by another 10-15 tenge per block. The inclusion of ash in the production process also reduces the cost of industrial waste disposal and reduces payments for landfill disposal, which is especially important for regions with large thermal power plants. Thus, the analysis of the production activities of Politech Construction LLP demonstrates that the introduction of ash-containing waste not only reduces the cost of production, but also generates a significant socio-environmental effect. In addition to direct financial indicators, the environmental impact is also an important factor. The use of ash-containing waste helps to reduce the burden on landfills of solid household waste, minimizes environmental damage and complies with the principles of "Green Kazakhstan". In the context of government policy aimed at sustainable development and resource conservation, this opens up additional opportunities for attracting subsidies and grants, as well as increases the investment attractiveness of the company (photo).

Conclusions

Ash and slag waste from the Almaty Thermal power Plant is both a source of soil contamination and a profitable and promising raw material in terms of chemical composition and properties. They can be attributed to man-made mineral raw materials, which, unlike natural ones, accumulate over time rather than deplete, which increases the prospects for their study and involvement in use. Consequently, the processing of ash and slag waste is a very promising area for innovation and investment, which has a multi-purpose focus and a beneficial impact on the ecological and economic development of industrial centers.

An analysis of the production activities of Politech Construction LLP clearly demonstrates that the introduction of ash-containing waste not only ensures a reduction in production costs and an increase in annual productivity, but also generates a significant socio-environmental effect.

Additionally, a high level of quality and a variety of types of building blocks allow the company to occupy a stable position in the market and contribute to achieving the strategic goals of the construction industry in Kazakhstan.

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Критерии авторства:
Авторы заявляют о равном вкладе каждого в работу над статьей.

Конфликт интересов:
Авторы заявляют об отсутствии конфликта интересов.

Информация о статье
Поступила в редакцию: 27.07.2026
Поступила после рецензирования: 16.08.2026
Принята к публикации: 18.08.2026

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Contribution:
The authors declare the equal contribution of everyone to the work on the article.

Conflict of interest:
The authors declare no conflict of interest.

Article info
Received: 27.07.2026
Revised: 16.08.2026
Accepted: 18.08.2026