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RESEARCH AND USE OF ASH AND SLAG WASTE FOR THE PRODUCTION OF BUILDING MATERIALS

Abstract. The article presents the results of a study of the main characteristics of ash selected from the ash dumps of CHP-3 in Almaty. It is shown that the operation of thermal power plants in Kazakhstan is characterized by a significant amount of accumulated (more than 500 million tons) ash and slag waste. It has been established that the storage and storage of ash and slag causes a very significant impact on the environment in the area of their location. Therefore, it is very important to address the issues of reducing the burden on the environment by developing technologies for the disposal of ash and slag and their use in road construction. The results of a study of the physical and technical characteristics of a binder based on bitumen and ash slag are presented. The study of samples using bitumen and slag binder showed that they meet the requirements of regulatory documents. The research results can be useful in solving the environmental problem of ash and slag waste disposal, which will reduce the volume of ash dumps, as well as free up occupied land for economic needs.

***Key words**: thermal power plants, coal combustion, ash and slag dumps, physical-chemical properties, secondary raw materials, building materials.*

Құрылыс материалдарын жасау үшін күл-қож қалдықтарын зерттеу және пайдалану

Андатпа. Мақалада Алматы қ. ЖЭО-3 күл үйінділерінен іріктелген күлдің негізгі сипаттамаларын зерттеу нәтижелері келтірілген. Қазақстанның жылу электр станцияларының жұмысы жинақталған (500 млн. тоннадан астам) күл-қож қалдықтарының едәуір мөлшерімен сипатталатыны көрсетілген. Күл қождарын сақтау және сақтау олардың орналасқан аймағында қоршаған ортаға айтарлықтай әсер ететіні анықталды. Сондықтан күл қождарын кәдеге жарату және оларды жол құрылысында пайдалану технологияларын әзірлеу арқылы қоршаған ортаға жүктемені азайту мәселелерін шешу өте өзекті болып табылады. Битум мен күл қождарына негізделген тұтқыр заттың физикалық-техникалық сипаттамаларын зерттеу нәтижелері ұсынылған. Битум-қож тұтқыр затты қолданатын үлгілерді зерттеу олардың нормативтік құжаттардың талаптарына сәйкес келетіндігін көрсетті.Зерттеу нәтижелері күл-қож қалдықтарын кәдеге жаратудың экологиялық проблемасын шешуде пайдалы болуы мүмкін, бұл күл үйінділерінің көлемін азайтуға, сондай-ақ шаруашылық мұқтаждықтары бар жерлерді босатуға мүмкіндік береді.

***Түйінді сөздер**: жылуэлектр станциялары, көмірдің жануы, күл-қож үйінділері, физикалық-химиялық қасиеттері, қайталама шикізат, құрылыс материалдары.*

Исследование и использование золошлаковых отходов для производства строительных материалов

Аннотация. В статье приведены результаты исследования основных характеристик золы, отобранной из золоотвалов ТЭЦ-3 г. Алматы. Показано, что работа тепловых электрических станций Казахстана характеризуется значительным количеством накопленных (более 500 млн тонн) золошлаковых отходов. Установлено, что складирование и хранение золошлаков вызывает весьма существенное воздействие на окружающую среду в зоне их расположения. Поэтому, весьма актуальным является решение вопросов снижения нагрузки на окружающую среду путем разработки технологий утилизации золошлаков и использования их в дорожном строительстве. Представлены результаты исследования физико-технических характеристик вяжущего вещества на основе битума и золошлаков. Исследование образцов с использованием битумозолошлакового вяжущего показали, что они отвечают требованиям нормативных документов. Результаты исследований могут быть полезными при решении экологической проблемы утилизации золошлаковых отходов, что позволит снизить объем золоотвалов, а также освободить занятые земли под хозяйственные нужды.

***Ключевые слова:** теплоэлектростанции, сжигание угля, золошлакоотвалы, физико-химические свойства, вторичное сырье, строительные материалы.*

Introduction

There are a significant number of thermal power plants in Kazakhstan. Every year, the volume of ash and slag waste (ASW) generated at thermal and power stations (TPS), GRES power plants (GRES), as well as in boiler houses is increasing. Fuel and electric power complex is one of the main «pollutants» of the natural environment. By burning coal, enterprises generate thermal energy and electricity. Negative aspect of this process is formation of coal combustion by-products – fly-ash (pulverized fuel ash) and slag [1, 2].

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 water and soil. The anthropogenic component of the 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 [3].

One of the largest thermal power plants in Kazakhstan is Almaty Electric Station JSC (JSC «AlES»), TPS-3, which provides energy to about 70% of consumers in the Almaty region. Waste from TPS-3 is not recycled, and current ash waste accumulates and occupies vast areas, which takes it out of land utilization. Storage of ash and slag wastes leads not only to the withdrawal of significant land areas, but also causes very significant pollution of almost all environmental components in the area of their location.

Development of electricity production and recycling of TPS waste, in particular, ash from coal combustion, is one of the main state priorities of Kazakhstan.

It is absolutely clear that there is a need to reduce the an-thropogenic burden through the introduction of regional regulations, changes in fees for pollution of water bodies and the use of energy waste in the manufacture of building materials. There is practically no processing of ash and slag waste on an industrial scale. About 8% of ash (less than 1.9 million tons) is processed from coal ash and slag waste produced by TPS and GRES in Kazakhstan at the research and production level. If the use of ASW remains at this level, then by 2030 the accumulated waste volume will reach 1 billion tons. According to expert estimates, invest-ments in the reconstruction of one ash and slag dump can reach 5 billion tenge, and the construction of a new one costs 12-13 billion tenge.

Therefore, today waste management has become particularly relevant as one of the key directions of a «green» economy development in Kazakhstan, that is, the preservation and effective management of ecosystems [4].

Of greatest interest to Kazakhstan is the experience of Germany, where the Federal Ministry of the Environment developed a Waste Prevention Program in 1972. In Germany, each manufacturer is interested in processing, and there are large processing complexes in the country.

Review of scientific papers [5-7] showed that there is a significant global practice of conducting research in the ash dumps of thermal power plants. In the CIS countries, the level of use of ash and slag from thermal power plants does not exceed 7-10%. In Denmark and Germany, ash and slag is used in the manufacture of building materials. In Poland, China and the United States, the percentage of ash and slag used is approximately 60%. Enterprises of Kazakhstan practically do not use ash and slag waste.

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

Currently, scientists at Satbayev University conducted research on the use of ash and slag waste for production of building materials [8-10].

Authors note that growth in scale of construction in Kazakhstan requires significant amount of mineral raw materials for building materials industry. Expansion of the mineral resource base of building materials industry can be ensured not only by searching for new deposits of non-metallic minerals, but also as a result of involving non-metallic raw materials in the production of technogenic waste. In view of the above, it is appropriate to use waste as a secondary product of production cycle. Thus, purpose of this paper is to study physicalchemical properties of ash and slag waste from the Ekibastuz coal combustion and to determine their potential for manufacture of demanded building materials.

Equipment and instruments of research

This research examines the ash and slag waste from TPS-3 of the Almaty GRES. The Almaty GRES unites 3 thermal and power plants (TPS-1, TPS-2, TPS-3), which provide heat and electricity to consumers in the city of Al-maty and the Almaty region of Kazakhstan. All TPSs use coal from the Ekibastuz field.

To conduct a research on the physical-chemical proper-ties of ash and slag waste from the TPS-3 ash dump coal combustion, ordinary samples are taken. The weight of indi-vidual samples ranges from 3-5 to 15-16 kg. Further, these ordinary samples are used to compile group samples.

To determine characteristics of input materials and composition of embedded mixtures and their physical and mechanical properties, standard methods were used, and XRF and ICS were used to identify their physical and chemical properties.

X-ray phase analysis (XPA) was carried out on a DRON-3M X-ray installation (RF) and X-ray structural analysis was carried out with a JCXA-733 «Superprobe» microanalyzer (Japan) with software, scientific research to study waste structure using laboratory polarizing microscope Leica ICH DM2500 (Switzerland), equipped with a powerful 100 W illuminator, which allows you to comfortably work with differential interference contrast; differential thermal analyzes (DTA) were carried out on a derivatographic device MOM-1500 D (Hungary); chemical analysis and microhardness tester PMT-3 (RF). Particle size analysis was performed by three methods: sieve analysis using a multi-frequency sieve analyzer MSA W/D-200 Kroosh Technologies Ltd.; granulometric analysis using a diffraction laser particle size analyzer Helos-KR with Quixel attachments; dispersion analysis in an apparatus for dispersion analysis of powders ADAP type.

Results and discussion

Using the X-ray DRON-3M diffractometer, an X-ray dif-fraction pattern of ash originating from TPS-3 has been obtained. The X-ray diffraction pattern is shown in Figure 1. An X-ray diffraction pattern is a graphical representation of the X-rays scattering on an ash sample. It displays the scat-tered radiation intensity depending on the angles at which the scattered radiation is recorded. An X-ray diffraction pattern may show peaks that correspond to different phases and components in the ash sample.

Detailed analysis of the X-ray diffraction pattern makes it possible to identify the presence of specific phases and de-termine their relative content. Peaks on the X-ray diffraction pattern correspond to certain crystalline planes, and their posi-tion and intensity can be used to determine the structural cha-racteristics of the material. As a result of the interpretation of this X-ray diffraction pattern, the following minerals have been identified in the following quantities, in % of the crystal-line phase: hematite Fe2O3 – 12.1%, quartz SiO2 – 32.4%, sillimanite Al2SiO5 – 25.9%, mullite Al4.95Si1.05O9.52 – 29.6%.

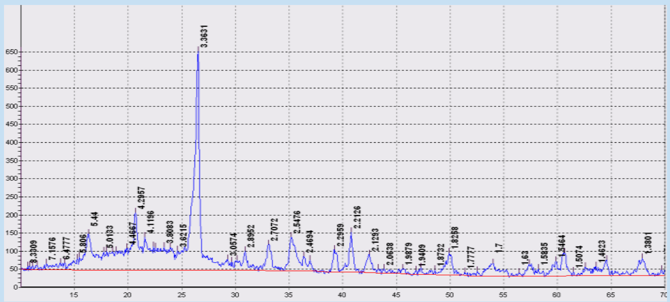

Figure 1. X-ray diffraction pattern from TPS-3.
Сурет 1. 3-ЖЭС кұ-қождарының рентгенограммасы.
Рис. 1. Рентгенограмма золы ТЭЦ-3.

Chemical composition, %: SiO2 – 57.7; Al2O3 – 29.6; (Fe2O3 + FeO) – 6.4; CaO – 1.1; MgO – 0.35; SO3 – 1.3; K2O – 0.03; Na2O – 0.52.

Thus, the use of the DRON-3M diffractometer provides qualitative and quantitative information on the ash phase composition to understand the structure and chemical charac-teristics of ash and slag waste and to serve as a basis for further research and use of these materials in various fields, including the manufacture of building materials. The results of the chemical analysis of the TPS dump ashes from the Ekibastuz coal combustion are presented in Table 1.

Table 1 clearly shows that the main component contained in the ash is silicon and aluminum oxide (from 57.7 to 63.9%), and there is also a high content of iron oxide, while the calcium oxide in the ash dump samples is significantly less than in the electrostatic filter samples. Most likely, free calcium oxide is converted into calcium carbonate upon reaction with carbon dioxide dissolved in water which is used to wash away the ashes through a slurry pipeline.

Table 1

Results of the chemical analysis of the TPS dump ashes

Кесте 1

ЖЭС күл-қождары химиялық талдауларының нәтижелері

Таблица 1

Результаты химического анализа золоотвалов ТЭС

Name of TPS, ash dumps and their elements	Composition, %									
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	TiO_2	MnO	P_2O_3	SO_3
Ekibastuz TPS	56,6	23,64	3,41	4,73	1,54	1,22	0,79	0,09	0,61	3,05
Ekibastuz GRES	63,9	25,50	0,80	5,70	0,10	0,90	1,20	-	-	0,20
Pavlodar TPS	57,7	25,26	2,48	10,1	1,66	0,50	0,02	0.24	-	0,07
Almaty TPS-3	57,7	23,97	4,95	6,20	1,19	1,06	-	-	-	0,08

Table 1 clearly shows that only the glass phase containing the microsphere has the main hydraulic activity, while the rest – mullite (($3Al_2O_3 \cdot 2SiO_2$), quartz (SiO_2), sillimanite (Al_2O_3), hematite ((Fe_2O_3) and carbon – do not have have hydraulic activity.

Figure 2 shows an electro-microscopic image of the ash. Ash particles are spherical, glassy and hollow, ranging in size from 1 to 50 μm. Large particles contain smaller spherical particles in their cavities, as shown by arrow in the Figure. On the surface of large particles, there are, as a rule, firmly «glued» tiny loose granules.

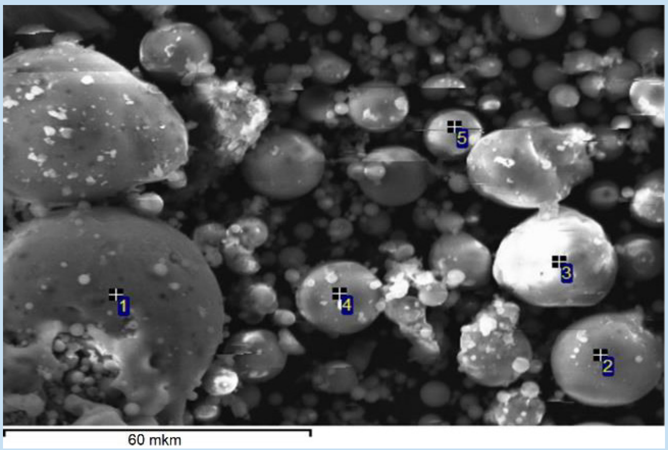

Figure 2. Micrograph of ash fractions in raster electron microscope.
Сурет 2. Растрлық электронды микроскоптағы күл фракцияларының микрофотосы.
Рис. 2. Микрофотография фракций золы в растровом электронном микроскопе.

Electron microscopy allows better understanding of microstructure of materials and their properties, which is of great scientific importance and makes it possible to deter-mine the surface area, hydrophobicity, thermal stability and strength of fly-ash. This is important for understanding how fly-ash interacts with the environment. The size and shape of fly-ash particles can also be used to assess their impact on human health. They can predetermine the ability of particles to penetrate human lungs and other organs. The presence of the smallest loose granules on the surface of large particles can also increase their toxicity. This is important for deter-mining the measures to be taken to protect human health in the area of possible exposure to fly-ash. Studying the particle structure and properties will help to further determine which materials can be used to create the most effective filters and other purification methods.

After conducting an experiment to study the properties of ash and slag waste, the next step is to produce ceramic samples containing these wastes. This requires a number of technological processes, including the preparation of raw materials, the formation of ceramic samples and their firing in a furnace at high temperature. After firing, a series of tests is carried out to study the physical and mechanical properties of ceramic samples with ash and slag waste and compare them with samples without such application. The test results allow us to conclude that the addition of ash and slag waste affects the properties of ceramic bricks, in particular, its strength and wear resistance.

Further work consisted in the manufacture of samples of ceramic bricks with the addition of ash and slag waste. In the work, a method was chosen for the production of laboratory ceramic bricks by plastic molding with different percentages of ash and slag waste and annealing at different temperatures. Figures 3, 4 and 5 show dependency graphs between the firing temperature and the ash content in the clay.

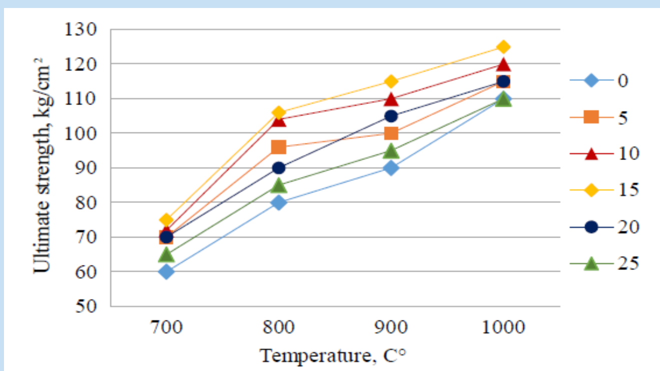

Figure 3. Dependency graph between ultimate strength and the firing temperature.
Сурет 3. Беріктік пен күйдіру температурасы арасындағы тәуелділік графигі.
Рис. 3. График зависимости предела прочности от темературы обжига.

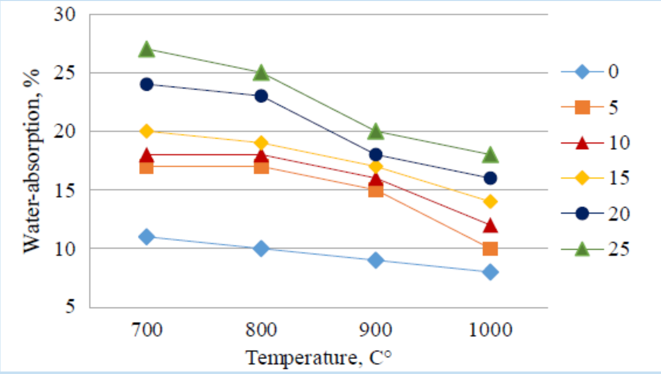

Figure 4. Dependency graph between water-absorption of a sam-ple and the firing temperature.
Сурет 4. Су тұтырлығы мен температурасы арасындағы тәуелділік графигі.
Рис. 4. График зависимости водопоглащения образца от температуры обжига.

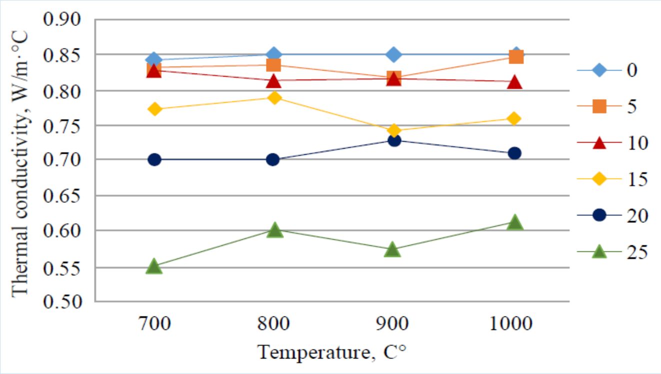

Figure 5. Dependency graph between thermal conductivity of a sample and the firing temperature.
Сурет 5. Жылу өткізгіштігі мен температурасы арасындағы тәуелділік графигі.
Рис. 5. График зависимости теплопроводности образца от температуры обжига.

An analysis of the performed research on ash and slag waste from the Ekibastuz coal combustion has revealed that thermal conductivity, ultimate strength and water-absorption depend on the amount of added ash and the firing temperature.

The higher the ash content in a brick is, the lower its ther-mal conductivity. Water-absorption increases with the increase in ash. The compressive strength also decreases with increas-ing ash content in bricks. The optimal percent-age ratio of add-ing ash and slag waste is 15% at 1000° of firing temperature.

The conducted research on ash and slag wastes from the Ekibastuz coal combustion has revealed that the use of these wastes as an additive to ceramic brick can be very effective. In this case, it is necessary to take into account not only the amount of added ash, but also the firing temperature, which also affects the material properties. The thermal conductivity of the brick is one of the key parameters, which is influenced by the addition of ash and slag waste. The ash content of a brick directly affects the level of the material thermal con-ductivity, and the higher the ash content, the lower the ther-mal conductivity. It has also been determined that the water absorption of brick increases with increasing ash content in the material. In addition, the compressive strength of a brick decreases when the ash content increases. The optimal per-centage ratio for adding ash and slag waste to ceramic brick is 15% at 1000° of firing temperature.

Conclusions

Analysis of the Ekibastuz ash chemical composition gives an idea of the composition of mineral substances of coal. The main components are silicon and aluminum oxides, as well as a significant amount of iron oxide. It is necessary to know the chemical composition of ash to decide whether it can be used in various sectors of the national economy.

One of the main indicators is granulometric composition. The higher the content of the microdisperse particles is, the higher the ductility of the material. In addition, the product will have greater strength and cohesion. The granulometric composition analysis indicates that 60% of the particles have a size from 10 to 70 μm. It can be seen from the data that the material is very finely dispersed.

Analysis of the chemical composition and other parame-ters shows that the waste can be used in the construction in-dustry. The use of ash and slag waste in various construc-tion industries will make it possible not to accumulate ash and slag waste at ash and slag dumps, thereby preserving the environ-ment and reducing the use of natural resources.

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