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Studying the properties of ash and slag waste for use in the manufacture of construction products

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Abstract

Purpose. The research purpose is to study the physical-chemical properties of ash and slag waste generated during the coal combustion at the Ekibastuz field in Kazakhstan, to determine the possibility of using waste as a secondary resource to reduce the negative human impact on the environment.

Methods. The research uses the methods of X-ray phase and differential thermal analysis, as well as chemical analysis. The X-ray phase analysis makes it possible to determine the phase composition and structure of ash and slag wastes, while differential thermal analysis is used to study their behavior with temperature changes. A chemical analysis is performed to determine the composition of ash and slag.

Findings. The chemical and granulometric composition of ash and slag waste from the Ekibastuz field coal combustion has been determined. Analysis of the ash chemical composition showed that its main components are silicon and aluminum oxides, as well as a significant amount of iron oxide. The results obtained confirm the possibility of using ash and slag waste as a secondary raw material to reduce the negative impact on the environment.

Originality. It has been revealed that the thermal conductivity, ultimate strength and water-absorption of ceramic brick samples depend on the amount of ash added and the firing temperature. The possibility of obtaining building materials with minimum cement content has also been substantiated, which is a new and promising approach, given the high cost of cement as the main building material.

Practical implications. The practical value of the research is in solving environmental problems associated with the use of ash and slag waste. Using these wastes as a secondary raw material, it is possible to reduce the anthropogenic burden on the environment, as well as the volume of ash dumps. In addition, vacant land previously occupied by ash and slag mixtures can be used for economic purposes.

Keywords: *coal combustion, ash and slag dumps, physical-chemical properties, secondary raw materials, building materials*

1. 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. The fuel and electric power complex is one of the main "pollutants" of the natural environment [1], [2]. By burning coal, enterprises generate thermal energy and electricity. The negative aspect of this process is the formation of coal combustion by-products – fly-ash (pulverized fuel ash) and slag [3]-[5].

The deterioration of the 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 [6]-[11]. 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 [12].

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. The 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.

The development of electricity production and recycling of TPS waste, in particular, ash from coal combustion, is one of the main state priorities of Kazakhstan. Figure 1 shows the volumes of ash and slag waste generation by regions of the republic in 2022.

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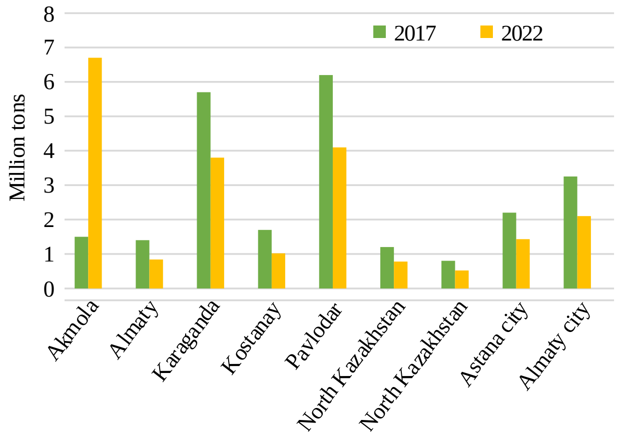

Figure 1. Ash and slag waste generation in the regions of the Republic of Kazakhstan

The oil-bearing Kazakhstan regions (Atyrau, Mangistau, West Kazakhstan, Aktobe and Kyzylorda) use gas fuel [13]. It is absolutely clear that there is a need to reduce the anthropogenic 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 [14]-[16]. There is practically no processing of ash and slag waste on an industrial scale [17]. 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, investments 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 [18].

Scientists of Kazakhstan in various years conducted research on the use of industrial waste instead of primary natural resources [19]-[21]. Thus, due to the acute shortage of Portland cement, industrial waste was actively used to produce concrete and reinforced concrete products in Kazakhstan. This decision was implemented by Kazakh scientists, but then the work was suspended due to lack of funding.

Today, many foreign countries have experience in the development of effective environmental and economic systems of waste-free technology [22]-[27]. This experience is useful for Kazakhstan in terms of using innovative solutions in the field of processing and recycling of ash and slag waste in domestic practice [28], [29]. The problem of slag utilization in construction remains a pressing challenge, since almost all research is limited to experimental development [30]-[32] All this makes it imperative to conduct targeted integrated research, both of the slag itself and of materials based on it. 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 [33].

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.

A review of previous scientific works has shown that there is a significant global practice of conducting research on ash dumps of thermal power plants [34]-[36]. 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.

The 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 in order to reduce the cost of building materials [37]-[39]. The use of solid waste from mining in the building materials industry is more economical than the manufacture of building materials based on the special extraction of mineral raw materials [40], [41].

At present, applied research and scientific-technical developments in the field of ash and slag processing technologies are carried out at Satbayev University [42]-[44] and its branch of the Central Laboratory for Certification of Building Materials (TseLSIM), where a mini-plant for the production of secondary raw materials based on production waste has been launched.

The works [45], [46] contain the research results of TseLSIM scientists on the use of production waste for the manufacture of building materials. The authors note that the growth in the scale of construction in Kazakhstan requires a significant amount of mineral raw materials for the building materials industry. The expansion of the mineral resource base of the 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.

Industrial processing of technogenic raw materials (wastes of beneficiation and processing, overburden and host rocks), close in composition to natural and used in traditional spheres, practically does not differ from the industrial processing of natural mineral raw materials. 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 view of the above, it is appropriate to use waste as a secondary product of the production cycle.

Thus, the purpose of this paper is to study the physical-chemical properties of ash and slag waste from the Ekibastuz coal combustion and to determine their potential for the manufacture of demanded building materials. In order to achieve the purpose set, it is necessary to solve the following tasks:

– determine the phase and chemical composition of the source ash;
– determine the ash granulometric composition;
– to test samples for compressive and tensile strength.

There are a number of advantages and benefits that can be derived from using ash and slag waste as a secondary product of the production cycle. Firstly, it will allow the efficient use of waste that was previously considered to be a problem and required handling or disposal. The use of ash and slag waste in the manufacture of building materials will reduce the volume of waste, the need to create ash dumps and the negative impact on the environment. Secondly, the use of ash and slag waste to produce building materials can help reduce production costs. Ash and slag waste can be used as an additional or substitute component in building mixtures, thus reducing the cost of expensive materials such as cement.

2. Materials and methods

By burning coal, TPS produces thermal energy and generates electricity. The negative aspect of this process is the formation of coal combustion by-products – fly-ash (pulverized fuel ash) and slag. The composition of the ash and slag material is determined by the quantitative ratio of its constituent minerals, which depend on the mineralogical composition of the source fuel part [47], [48].

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 Almaty and the Almaty region of Kazakhstan. All TPSs use coal from the Ekibastuz field.

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

The sampling process is performed in order to obtain representative samples of ash and slag waste, which most accurately reflect the composition and properties of the total waste volume at the ash dump. Sampling of ordinary samples with different weights makes it possible to take into account possible variations in the composition and structure of the waste in different sections of the ash dump.

After taking ordinary samples, these samples are mixed in appropriate proportions to obtain group samples. Group samples are composite samples representing the average composition and properties of ash and slag waste at the TPS-3 ash dump. Such an approach to sampling and compilation of samples provides reliable and representative data on the physical-chemical properties of ash and slag waste at the ash dump. These data will be used to further study the ash composition, phase composition, granulometry and strength testing of building materials derived from these wastes. Detailed sampling and compilation of samples are an important part of the methodology for studying the physical-chemical properties of ash and slag waste, which ensures the reliability and representativeness of the results obtained.

To determine the phase composition of cement and ash, as well as to assess their strength properties, an upgraded DRON-3M diffractometer with software is used. The diffractometer operates on the basis of X-ray diffraction and makes it possible to analyze the crystalline structure of materials [49]. The studies are conducted on CuK α radiation, which is a typical X-ray source for analyzing crystalline materials. To obtain X-ray diffraction patterns, the range of 2θ (angles) from 10 to 70º is used.

The resulting X-ray diffraction patterns are processed using specialized software that allows analysis and interpretation of the obtained data. The software makes it possible to determine the peak values, intensity and position of the peaks on the X-ray diffraction patterns, which provides information on the phase composition of the materials. A qualitative analysis of the cement and ash phase composition makes it possible to determine which components are present in the materials and in what quantities. This is important for understanding the structural and chemical properties of materials, as well as their impact on strength performance [50]-[52].

The use of an upgraded diffractometer and software ensures the accuracy and reliability of the analysis results of the material phase composition. This approach provides detailed information on the crystalline structure of cement and ash, which is important for further study of their properties and applications in construction.

Knowledge of the chemical composition of ash and slag waste is a necessary condition for assessing its properties and determining whether it can be used in various sectors of the national economy. To determine the chemical composition of ash and slag waste, ash samples are taken from electrostatic filters of ash and slag dumps according to RD 34.09.603-88 “Methodological instructions for organizing control of the composition and properties of ash and slag sold to consumers by TPS.” This methodology makes it possible to analyze the content of various elements in ash and slag, which is important for assessing their possible use in the manufacture of building materials or other industries.

The fly-ash chemical composition is determined using an energy dispersive X-ray fluorescence spectrometer EDX-8000. This instrument makes it possible to analyze the chemical composition of materials by measuring the X-ray radiation caused by ray treatment of a sample with an electron beam. Thus, an accurate and reliable technology is used to obtain data on the fly-ash chemical composition.

The granulometric composition is analyzed using an Analizette 22 MicroTec Fritsch GmbH (Germany). The fly-ash micrograph is taken with a Superprobe-733 raster electron microscope with software.

The physical-mechanical ash properties are determined according to the technical requirements of GOST 30744-2001 and GOST 8736-2088. The samples are fired in a SNOL 6.7-1300 muffle furnace, and a BL-10 laboratory mixer is used for mixing the samples. The strength test of samples is performed 1 day after steaming and 7, 14 and 28 days after water storage of steamed samples. The fly-ash content in the composition of binders is 5, 10, 15 and 20% according to weight. The samples are tested for compressive strength in accordance with GOST 10180-90 using a PM-20MG4 laboratory press with software, thanks to which the data obtained show their grade strength.

3. Results and discussion

3.1. Chemical and phase composition of ash

Using the X-ray DRON-3M diffractometer, an X-ray diffraction pattern of ash originating from TPS-3 has been obtained. The X-ray diffraction pattern is shown in Figure 2. An X-ray diffraction pattern is a graphical representation of the X-rays scattering on an ash sample. It displays the scattered 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.

A detailed analysis of the X-ray diffraction pattern makes it possible to identify the presence of specific phases and determine their relative content. Peaks on the X-ray diffraction pattern correspond to certain crystalline planes, and their position and intensity can be used to determine the structural characteristics 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 crystalline phase: hematite Fe_2O_3 – 12.1%, quartz SiO_2 – 32.4%, sillimanite Al_2SiO_5 – 25.9%, mullite $Al_{4.95}Si_{1.05}O_{9.52}$ – 29.6%.

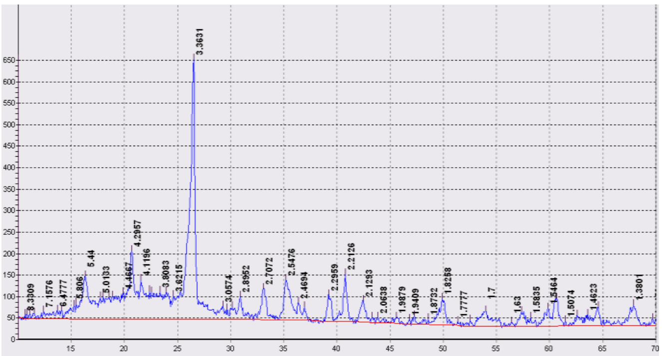

Figure 2. An X-ray diffraction pattern from TPS-3

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.

Thus, the use of the DRON-3M diffractometer provides qualitative and quantitative information on the ash phase composition to understand the structure and chemical characteristics 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

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	56.60	23.64	3.41	4.73	1.54	1.22	0.79	0.09	0.61	3.05
Ekibastuz GRES	63.90	25.50	0.80	5.70	0.10	0.90	1.20	–	–	0.20
Pavlodar TPS	57.70	25.26	2.48	10.10	1.66	0.50	0.02	0.24	–	0.07
Almaty TPS-3	57.70	29.60	1.10	6.24	0.35	0.03	–	–	–	1.30

Analyzing the ash phase composition, it can be concluded that only the glass phase containing the microsphere has pozzolanic and 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 (C) do not have puzzolanic and hydraulic activity.

In addition, the ash contains the following microelements: P, Sc, Mn, Pb, Ti, As, Zr, Ge, Ga, W, Ni, Cr, which do not exist independently in the ash, do not form independent compounds, but are part of minerals and glass phase. Specific surface area – 290 m^2/kg; true density – 2.1 g/cm^3, bulk density – 780 kg/m^3 [53].

Table 2. Distribution of the ash phase composition depending on its fraction

Particle size, μm	Distribution of the phase composition by fraction, %				
	mullite	α-quartz	sillimanite	carbon	glass phase (occupied area, cm^2)
500	28	54	–	18	6
450	44	21	24	11	14
250	48	19	25	11	14.3
100	46	18	28	8	14.5
90	45	25	22	8	17
80	42	20	31	7	18
63	47	17	29	7	20
50	50	21	29	–	22
45	47	25	28	–	23
40	51	14	35	–	23

Table 2 shows the distribution of the ash phase composition depending on its fractional composition. Analyzing the data of this table, the following can be stated:

– ash is mainly represented by a fraction consisting of particles of 100 μm in size – 25.8%, 80 μm in size – 12.12%, 50 μm in size – 21.46%, 45 μm in size – 21.38%; in total they are 80.76%;

– the composition of particles with a size of 500 μm, which is represented by mullite (28%), α-quartz (54%), carbon (18%) and a small amount of glass phase, stands apart (occupying a halo area on the X-ray diffraction pattern reaches 6 cm^2; their content of the total fly-ash amount is small – only 0.14%;

– the unburned carbon content on the X-ray diffraction patterns is fixed only in the composition of large fractions – from 500 to 63 μm; within these fractions, its content naturally decreases: 18-7% − from coarse to fine fraction.

Figure 3 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 an arrow in the Figure. On the surface of large particles, there are, as a rule, firmly "glued" tiny loose granules.

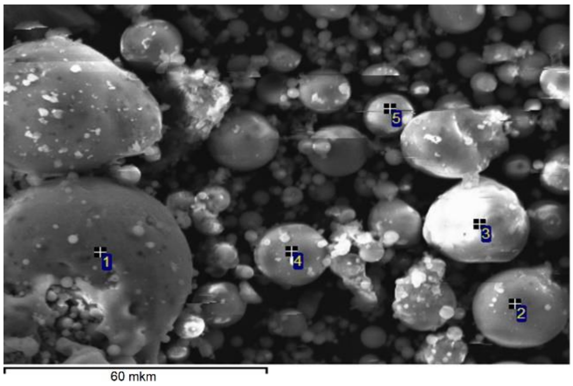

Figure 3. Micrograph of ash fractions in raster electron microscope

Electron microscopy allows a better understanding of the microstructure of materials and their properties, which is of great scientific importance and makes it possible to determine 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 determining 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.

3.2. Granulometric composition

One of the main indicators of raw materials is their granulometric composition. The higher the content of the microdisperse particles is, the higher the ductility of the material is. Therefore, the raw materials will have a high cohesion, which will have a positive impact on the strength characteristics of finished products [54].

The higher the microdispersion content of the particles in the material, that is, the more particles with a size of less than tenths of a millimeter, the greater the ductility of this material. Such ductility gives the material the ability to change its shape without breaking or cracking. This can be an important factor in the production of materials subjected to thermal processing. Materials with a high content of microdisperse particles can be more elastic, flexible and capable of being molded, which ensures a high quality of the manufactured product. However, high microdispersion of the material can also reduce the material strength, especially when in contact to with other materials or when exposed to high temperatures and pressures. Therefore, in production, it is necessary to balance the content of microdisperse particles to achieve optimal ductility and strength of the material.

The ash and slag waste distribution into fractions can be attributed to various factors, such as the coal combustion process, coal characteristics and TPS operating conditions. During the combustion of coals, various particles are formed, and their sizes are determined by the processes of fragmentation and separation during combustion. Also, the method of processing ash after combustion can have an impact on the granulometric composition.

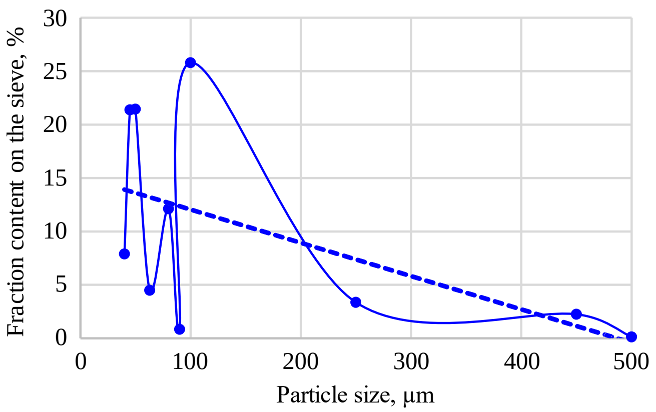

Figure 4. Fraction distribution on sieve depending on the particle size

The ash and slag waste distribution by fractions shows that the prevailing share of waste has a particle size ranging from 0.04 to 0.1 mm, where the total percentage is about 75%. This may be conditioned by the coal combustion process peculiarities, which results in particles of this size. Smaller particles (less than 0.04 mm) and larger ones (more than 0.1 mm) make up a smaller part of the total waste volume.

There is also a loss during firing of ash and slag waste, which is about 3%. This may be caused by the firing process, in which part of the material is lost in the form of gaseous products or volatile components. In general, the information obtained on granulometric composition and losses during firing of ash and slag wastes provides relevant data for further research and possible use of these wastes in building materials or other industrial processes.

3.3. Testing of samples

Further work consists in the manufacture of ceramic brick samples with the addition of ash and slag waste.

After conducting an experiment to study the properties of ash and slag waste, the next step is to make ceramic samples that include this waste. 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 a high temperature. After firing, a series of tests are conducted to examine the mechanical-physical properties of ceramic samples with ash and slag waste and to compare them with samples without such an application. The test results lead to the conclusion that the addition of ash and slag waste affects the properties of ceramic bricks, in particular, their strength and wear resistance.

During the research, a method is chosen for producing laboratory ceramic bricks by the method of plastic molding with a different percentage content of ash and slag waste and firing at different temperatures. Figures 5, 6 and 7 show dependency graphs between the firing temperature and the ash content in the clay.

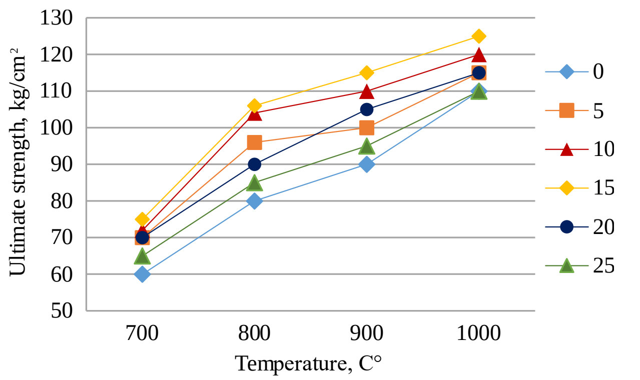

***Figure 5.** Dependency graph between ultimate strength and the firing temperature (0-25% is the ash content in the clay)*

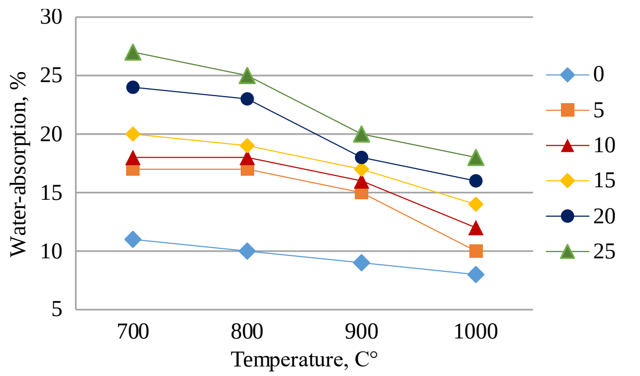

***Figure 6.** Dependency graph between water-absorption of a sample and the firing temperature (0-25% is the ash content in the clay)*

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.

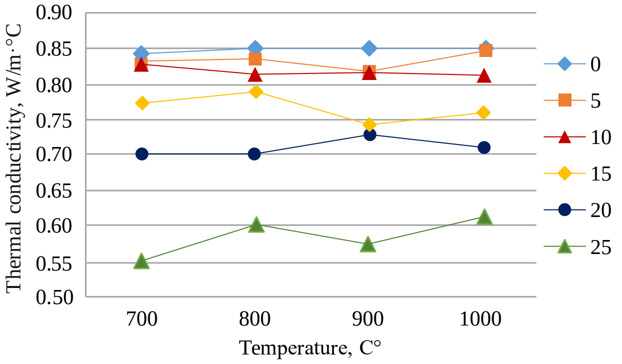

Figure 7. Dependency graph between thermal conductivity of a sample and the firing temperature (0-25% is the ash content in the clay)

The higher the ash content in a brick is, the lower its thermal conductivity. Water-absorption increases with the increase in ash. The compressive strength also decreases with increasing ash content in bricks. The optimal percentage ratio of adding 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 conductivity, and the higher the ash content, the lower the thermal 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 percentage ratio for adding ash and slag waste to ceramic brick is 15% at 1000° of firing temperature.

Based on the research results, it is possible that future scientific research will focus on optimizing the processes for the production of ceramic bricks using ash and slag waste. It would be interesting to study the influence of various parameters on the properties of bricks, such as the size of the ash and slag waste particles, the cooling rate and the firing duration. In addition, further research could focus on finding alternative materials for use in brick production, which could lead to the development of more sustainable and environmentally friendly building materials.

4. 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 parameters shows that the waste can be used in the construction industry. The use of ash and slag waste in various construction industries will make it possible not to accumulate ash and slag waste at ash and slag dumps, thereby preserving the environment and reducing the use of natural resources.

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Дослідження властивостей золошлакових відходів та їх використання при виробництві будівельних виробів

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Мета. Вивчення фізико-хімічних властивостей золошлакових відходів, які утворюються при спалюванні вугілля з Екібастузького родовища в Казахстані, для визначення можливості їх використання як вторинних ресурсів для зниження негативного впливу на навколишнє середовище.

Методика. У дослідженні використовувалися методи рентгенофазового, диференційно-термічного та хімічного аналізу. Рентгенофазовий аналіз дозволив визначити фазовий склад та структуру золошлакових відходів, а диференціально-термічний аналіз використовувався для вивчення їх поведінки при зміні температури. Хімічний аналіз було проведено для визначення складу золошлаків.

Результати. Визначено хімічний та гранулометричний склади золошлакових відходів від спалювання вугілля Екібастузького родовища. Аналіз хімічного складу золи показав, що її основними компонентами є оксиди кремнію, алюмінію та значна кількість оксиду заліза. Отримані результати підтверджують можливість використання золошлакових відходів як вторинної сировини для зниження негативного впливу на навколишнє середовище.

Наукова новизна. Встановлено, що теплопровідність, міцність і водопоглинання зразків керамічної цеглини залежать від кількості доданої золи та температури обпалу. Також обґрунтовано можливість отримання будівельних матеріалів з мінімальним вмістом цементу, що є новим і перспективним підходом, враховуючи здорожчання цементу як основного будівельного матеріалу.

Практична значимість полягає у вирішенні екологічних проблем, пов'язаних із використанням золошлакових відходів. Використання цих відходів як вторинної сировини дозволить знизити антропогенне навантаження на навколишнє середовище та зменшити обсяг золовідвалів. Крім того, звільнені земельні ділянки, що раніше були зайняті золошлаковими сумішами, можна буде використовувати в господарських цілях.

Ключові слова: *спалювання вугілля, золошлакові відвали, фізико-хімічні властивості, вторинні ресурси, будівельні матеріали*