Use of bottom ash materials in the construction industry

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Abstract. It is possible to use waste from the energy production of thermal and electrical energy, in the form of ash and cinder, as a substitute for natural mineral raw materials in the production of construction materials and products. Bottom ash, being a valuable raw component for the production of mortars, concrete and reinforced concrete, under certain conditions, provides a significant increase in the quality of the multicomponent matrix, and improves the construction, technical and thermal insulation properties of the finished product. Bottom ash from TPPs is an inexpensive construction material which increases the basic construction, technical and thermal insulation properties of the resulting construction products, which leads to a decrease in heat losses among consumers and, ultimately, to a decrease in the cost of housing under construction. This contributes to the implementation of the state programs “Affordable Housing” and “Low-Rise Construction”. One of the largest consumers of bottom ash mixtures could be road construction within the framework of the state program “Development of the Transport System”. Moreover, the use of bottom ash from TPPs is an indicator of the state of the art in power engineering and construction. However, there are a number of problems that one has to face when using bottom ash in industry, the main problem being unstable fractional composition and physicochemical characteristics that do not meet technical requirements. In their turn, the physicochemical characteristics of bottom ash from TPPs are formed in the course of conversion of the fuel mineral matter during combustion in boiler plants. Knowing the behavior of the coal mineral components during combustion, it is possible to solve the problem of choosing the optimal combustion modes for the production of bottom ash materials with the chemical and mineralogical composition required by consumers, while not reducing the efficiency of the boiler plant. Thus, TPP bottom ash is becoming a valuable mineral raw material - bottom ash materials for replacing nonmetallic materials in the construction sector.

The implementation of the national program “Affordable Housing” required the construction industry to significantly increase the production of construction materials. There is a need to provide the industry with the required amount of raw materials. In a number of regions, it is impossible to satisfy the demand for construction materials by materials produced in these regions. Therefore, problems arise associated with the extraction of natural mineral raw materials, since high demand entails illegal extraction of raw materials, severe environmental consequences, a decrease in the quality of raw materials with a sharp rise in prices, which leads to an additional increase in construction costs [1].
Therefore, experts are increasingly turning to innovative methods of obtaining inert materials. The option of reducing the prime cost of housing under construction through the processing and direct use of bottom ash from thermal power plants (TPPs), as well as other waste from the energy industry, remains one of the most promising.

Today, Russia spends several times more irreplaceable natural resources on the production of most of the construction materials than countries where great attention is paid to resource conservation.

In developed countries, it has long been prohibited to develop quarries in order to obtain sand, gravel or crushed stone as aggregates for concrete. They make up for the lack of dense aggregates through the processing of man-made waste, and recently, to a large extent, waste from TPPs [1].

In Russia, when it comes to ash and cinder from coal-fired thermal power plants, the term “bottom ash waste” (BAW) is widely used. Power plants offer consumers literally waste, and not a technologically modified product with characteristics complying with the requirements of construction regulations [2].

In addition, ash dumps from TPPs occupy large areas, and their maintenance requires significant operating costs, which also affect the increase in the prime cost of energy production. They are also a source of environmental pollution, pose a danger to public health and a threat to the flora and fauna of nearby areas.

The concept of “waste” primarily indicates the absence of technologies that could convert them into a target product. Such terminology makes it difficult to understand the possibility of practical application of TPP bottom ash in various industries, in particular construction, and its commercialization as a marketable product.

In other countries, bottom ash is called by-product, or associated product of coal combustion, namely bottom ash materials (BAM). Power plants carry out pre-sale preparation of the product, bringing the characteristics of bottom ash up to the requirements of official construction regulations.

It is worth noting the fact that in the USA, builders are legally required to use TPP ash in concrete and mortars. Violators are subject to economic sanctions by the state. In China, TPP bottom ash is given to consumers free of charge. Poland uses powerful economic levers to stimulate the use of bottom ash [2].

In previous years in Russia, over 400 research and development organizations were involved in the disposal of bottom ash materials. They have developed about 300 different technologies for processing bottom ash waste from TPPs in 23 directions corresponding to the world level, but, as a rule, only a small part can be implemented in practice. This is confirmed by the low level of use of bottom ash in Russia, the annual consumption is no more than 10% of the annual output, while in Western countries this figure reaches 70-95%, and in the Netherlands and Denmark - almost 100%. Moreover, the developed Russian technologies are mainly aimed at using bottom ash from the existing ash dumps of TPPs.

Technically, with the development of processing technology, the shortage of such secondary resources as fly ash and cinder does not threaten TPPs until the world's coal reserves disappear. In addition, according to the most conservative estimates of experts, coal reserves in the Russian Federation will last for at least 200 years.

Bottom ash, being a valuable raw component for the production of mortars, concrete and reinforced concrete, under certain conditions, provides a significant increase in the quality of the multicomponent matrix, improves the construction, technical and thermal insulation properties of the finished product, and fully meets the requirements of sanitation, including the radiological aspect [4].

Some examples of modern construction using ash [3]: Eisenhower Expressway (Chicago); Picasso Tower in Madrid (height 157 m); Commerzbank Tower in Frankfurt; Puylaurent Dam in France (73 meters high, 220 meters long); the Channel Tunnel connecting France and the UK; the runway at Eindhoven Airport in Holland; the tallest building in the world Burj Dubai in the city of Dubai, etc.

World and domestic experience shows that bottom ash waste is a valuable mineral raw material - bottom ash materials for replacing nonmetallic materials in the construction industry. Furthermore, only the construction industry can cope with the scale of ash and cinder formation from TPPs.
In the construction industry, TPP bottom ash can be used in the production of: silicate bricks, wall building materials, gas-silicate concrete blocks and products (including reinforced ones), dry pack mortars, hydraulic binders and additives to Portland cement and pozzolanic cement, thermal insulation materials (similar to glass wool, basalt or mullite wool for various technical purposes), construction fillers, sealing materials (as a filler), finely ground fillers, gas silicate concrete blocks and autoclaved products - heat-insulating wall building material, etc.

During the construction and repair of heating systems, the following soil materials are used: crushed stone, sand, crushed stone-gravel-sand mixtures. For example, when laying reinforced concrete trays and supports, installing heat chambers, it is often necessary to replace existing soil that does not meet the criteria for density, bearing capacity, and frost resistance. Such soils usually include loose and clayey soils (vegetation layer of soil, dust sands, peat, silt, clay, clay loam, sand loam). When laying reinforced concrete products, it is recommended to remove these soils to the existing compacted layers or layers that can be compacted to the required design density. If the existing soil is prone to heaving, the soil is replaced to the depth of freezing. Non-sagging, frost-resistant soil (usually crushed stone or crushed stone-gravel-sand mixture) is laid after compaction of the existing bed. It can be a frost-resistant bottom ash mixture (BAM) of large or medium composition with layer-by-layer compaction [5].

Considering the variety of the listed construction products that can be obtained using TPP bottom ash, it is possible to implement the state programs “Affordable Housing” and “Low-Rise Construction”.

As an example, let us give a diagram of the integrated use of industrial waste in construction, showing the possibility of constructing some conditional object, for example, a cottage (figure 1), during the construction of which from the foundation to the roof, construction materials and products made from man-made raw materials would be used to the maximum [6]. The presented diagram shows the possibility of using not only the man-made raw materials of TPPs, waste from the combustion of coal, ash and cinder (right branch), but also waste from other industrial productions (left branch).

Figure 1. Diagram of integrated use of industrial waste in construction.
Road construction could be one of the largest consumers of bottom ash mixtures. In construction estimates for roads, at least 50% of the cost is the cost of materials. The construction of 1 km of a road requires, depending on its category and local conditions (terrain, climate, etc.), on average: 6 - 60 thousand m$^3$ of soil, often imported, for the construction of the subgrade; 1.5 - 6.0 thousand m$^3$ of sand for drainage and frost protection layers; 0.8 - 5.4 thousand m$^3$ of crushed stone or soil reinforced with binders for the base; 1.1 - 4.7 thousand tons of asphalt concrete or 1.2 - 4.8 thousand m$^3$ of cement concrete, which requires, respectively, 55 - 235 tons of bitumen or 480 - 1700 tons of cement [7]. When constructing road pavements, there are ways to save traditional materials. As a rule, it is still impossible to abandon asphalt concrete and cement concrete on the roads of higher categories, but when building road bases, the problem of saving traditional scarce materials by using bottom ash materials can be solved in many cases.

One of the promising ways to utilize bottom ash waste from TPPs of PJSC Irkutskenergo is the production of agglomerite gravel. Agglomerite gravel is a very high quality lightweight aggregate for concrete, in addition, it is a very good thermal insulation construction material. A lot of bottom ash from TPPs of PJSC Irkutskenergo have a composition that meets the requirements for the production of agglomerite gravel: SiO$_2$ – 55±10%; Al$_2$O$_3$ – 25±10%; Fe$_2$O$_3$ – 10±8%; CaO + MgO – up to 12%; Na$_2$O + K$_2$O – up to 5%; SO$_3$ – up to 3%, while the bulk density should be 700-900 kg/m$^3$ and the content of coal residues in ash should not exceed 10-15%.

However, there are factors that restrain the use of TPP bottom ash in the production process, the main of which is its instability in chemical and mineral composition, the content of alkali metal oxides and unburned fuel. Therefore, in order to use BAW in industry, additional processing or processing into another product, BAM (“secondary”, “man-made” raw materials) is required.

Therefore, when solving the listed tasks, it is necessary to take into account the interests of both power engineers and builders, since only a systematic approach will make it possible to feel significant economic and environmental effects, both in the construction industry and in the energy industry.

When developing directions for obtaining and using BAM from TPPs, it is necessary to strive to apply inexpensive, environmentally friendly and highly efficient processing methods, mainly at the stage of direct formation and redistribution of mineral compounds of the fuel in the process of grinding, and then combustion.

Bottom ash from TPPs is 98-99% composed of bound compounds of oxides of silicon, aluminum, iron, calcium, sodium, titanium, sulfur, etc. Of the trace elements, bottom ash can contain boron, molybdenum, strontium, lead, nickel, cobalt, scandium, etc. According to its chemical composition, it is classified into high-calcium (containing more than 20% CaO) and acidic (less than 20% CaO). Priority areas of use in various industries are determined depending on the content of calcium oxides and the main indicators of hydraulic activity (basicity modulus, silicate modulus, quality factor).

The composition and properties of BAM depend primarily on the characteristics of the mineral part of the initial fuel, the technology of its combustion (boiler operating conditions).

The processes that determine the physicochemical characteristics of bottom ash are formed in the course of conversion of the mineral matter, which takes place in the combustion chamber (in the zone of active combustion). Factors affecting the conversion of the mineral part of coal during combustion are: combustion temperature, the amount of oxidizer supplied to the furnace (excess air ratio), the dwelling time of the fuel particle in the furnace, the composition of the medium (combustion products) and the contact conditions between the individual fuel particles. Since these parameters can be changed within certain limits during the design of combustion devices or maintained during the operation of steam generators, the conversion processes of the mineral part of the fuel can also be controlled within certain limits [8].

Knowing the behavior of the coal mineral components during combustion, it is possible to solve the problem of choosing the optimal combustion modes for the production of bottom ash materials with the chemical and mineralogical composition required by consumers, while not reducing the efficiency of the boiler plant [9]. Thus, the boiler unit is transformed into an energy-technological boiler-house plant for the production of not only heat energy, but also bottom ash products. High-temperature
thermochemical processes are fundamental to the integrated energy-technological use of solid fuels. When placing the high-temperature energy-technological process of obtaining bottom ash materials of a certain composition into the traditional technological scheme for the production of heat and electric energy, it is necessary to take into account the numerous physicochemical processes occurring during the combustion of solid fuel. In addition, an improvement in the final composition of the resulting bottom ash can be achieved by adding various mineral compounds, for example, calcium-containing ones.

During combustion in the furnace chamber of a boiler under certain (operating) conditions, the mineral components of the fuel convert, which is characterized by thousands of reactions with the decomposition of the initial ones, the formation of new mineral compounds and their interaction [8]. Moreover, the conversion of the mineral compounds of coals in the furnaces of boilers is mainly reduced to a simplification of the general mineral composition (oxides of calcium, silicon, aluminum, etc.), and the resulting compounds are quite uniform for coals of various deposits, for example, Ca$_3$SiO$_5$, Mg$_2$SiO$_4$, Mg$_2$Al$_4$Si$_9$O$_{18}$, Al$_2$SiO$_{13}$ and others (figure 2), but their number depends on the initial mineral composition of the fuel [9].

The most attractive compounds from those shown in Fig. 2, for example, for the production of Portland cement are calcium-containing ones, namely alite (Ca$_3$SiO$_5$), since the basis of the mineralogical composition of Portland cement consists of 45-65% of 3CaO × SiO$_2$, or Ca$_3$SiO$_5$; the rest is 15-30% (2CaO×SiO$_2$, or Ca$_2$SiO$_4$); 3-14% (3CaO×Al$_2$O$_3$); 10-18% (4CaO×Al$_2$O$_3$×Fe$_2$O$_3$). Chemical composition of Portland cement (without additives), % by weight: 62-76% CaO; 20-23% SiO$_2$; 4-7% Al$_2$O$_3$; 2-5% Fe$_2$O$_3$; 1-5% MgO.

![Diagram showing the conversion of the composition of the fuel mineral part along the height of the furnace of the boiler unit.](image)

**Figure 2.** Conversion of the composition of the fuel mineral part along the height of the furnace of the boiler unit.

To implement the proposed method for obtaining BAM of a certain composition, it is necessary to take into account not only the economic effect in the construction industry, but also the energy efficiency of the TPP equipment.

The main thing in the proposed methodology for energy-technological processing of coal in order to obtain useful bottom ash products of a certain composition is to create such conditions so that the
efficiency of the boiler plant for steam is not lower than with the traditional scheme of heat production. Then not only will the consumers be satisfied, but also the efficiency of the TPP will be increased.

A systematic approach to the production and use of BAM is to take into account the environmental, energy, industrial-technological and construction-technological aspects of the problem.

Considering the above, we can draw the following main conclusions:

Reducing the cost of housing under construction can be achieved through the processing and direct use of BAM as a replacement for natural mineral raw materials in the production of construction materials and products. The use of bottom ash from TPPs makes it possible to use inexpensive construction material and to increase the basic construction, technical and thermal insulation properties of the resulting construction products. This contributes to the implementation of the state programs “Affordable Housing”, “Low-Rise Construction” and “Development of the Transport System”.

The use of bottom ash from TPPs is the most important indicator of the state of the art in power engineering and construction. TPP bottom ash is a valuable mineral raw material - bottom ash materials for replacing nonmetallic materials in the construction sector. The use of bottom ash not only makes it possible to reduce the consumption of non-renewable natural resources, but also reduces the burden on the environment.

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