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INCREASING THE EFFICIENCY OF THE USE OF THERMAL POWER PLANTS WASTE IN ROAD CONSTRUCTION AND REPAIR

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Abstract. The results of literary studies on the level of ash-slag waste accumulation, its low utilization and use in Ukraine are presented. The results of previous years' research are shown, which indicate the possibility of their wide application in road construction. The main reasons for inhibiting the use of ash-slag waste in the road industry are indicated. Attention is paid to the emergence of more favourable conditions for increasing the efficiency of the use of ash-slag waste for the construction, reconstruction, repair and maintenance of roads and streets in the current economic conditions.

Key words: ash-slag waste, road construction, bituminous and mineral mixtures, pit repair of the road surface.

1. Introduction

According to the national legislation of Ukraine the use of industrial large-tonnage solid waste is an important state task that addresses the priorities of further development of the national economy and environmental protection, and aims at:

– increase in the efficiency of the use of material and energy resources;

– reduction of anthropogenic impact and its effects on the environment and improvement of the environmental situation;

– exploring the possibilities of using waste as raw material for different industries.

At the same time, many years of energy and raw materials specialization as well as the low technological level of the Ukrainian industry have made it one of the countries with the highest absolute volumes of waste generation and accumulation. Nowadays thermal power plants (TPP) on organic fuel make up the basis of energy of Ukraine. They provide 75–80 % of all electricity production [1]. The development of thermal energy is forecasted with the predominant use of coal, the share of which in the fuel balance will be 85.1 % in 2030. In the process of coal burning for heat and power electricity a significant amount of ash and slag is produced. On the territory of Ukraine there are 25 powerful thermal power plants and a considerable number of boiler-houses, thermal power plants and other enterprises of this branch.

During the year, they produce about 30 million tonnes of ash-slag waste, which is a major environmental problem for the country [2]. The ash dumps at most power plants are overfilled. If this problem is not taken care of, such power plants can be shut down and removed from the grid in the coming years. Further waste disposal requires the construction of new or expansion of existing ash dumps, which in turn leads to the alienation of large areas and environmental pollution [3–7]. The analysis of modern research shows that the level of damage to biosystems in the sanitary zone of ash dumps is estimated as "above average", and the environmental situation is characterized as "unsatisfactory" [3]. However, in Ukraine only about 10 % of ash-slag waste is utilized and used, that is more than 25 million tons of slag waste, mainly received by hydraulic removal, is placed in ash dumps of TPPs annually in addition to the previously accumulated, the amount of which is more than 1.5 billion tons now. At the same time, the experience of most countries in the world shows that it is possible to use more than 50 % of ash waste. In many countries, the use of ash slag in the production of building materials has reached almost 100 % of their annual output (Germany, Denmark, most US states and other countries), while in Germany it is generally forbidden to have ash dumps [2, 8].

Experts dealing with the problem of ash-slag waste believe that the main purpose of energy is not to recycle their entire volume, but to create objective conditions for maximum use in the production of commodity products, including their own production [2, 6–11]. Among the main reasons that determine the low level of utilization of ash-slag waste and hinder the further increase in its use to the average European level are the lack of technical policy and systematic approach to solving this problem in the country and, consequently, the lack of economic interest of the national economy sectors. Utilization of ash and slag requires the solution of a whole complex of issues: from the development of technical conditions for their application, technological lines for their processing, transportation and loading and unloading means, to the restructuring of the psychology of businessmen regarding the use of secondary mineral resources [2, 9]. At the same time, it is considered that in order to successfully solve the problem of utilization and use of ash and to minimize environmental damage, it is necessary first of all to ensure separate removal of ash and slag and create the possibility of 100 % collection and shipment of dry ash.

2. Current experience in the use of ash and slag waste in road construction

Road construction is one of the potentially largest heavy tonnage consumers of ash and slag waste [2, 6–11]. At this stage of economic development, Ukraine has a significant financial need to build roads of the European level. In the construction of motor roads more than 60 % of their cost is the cost of soil for the erection of earthenware and road-building materials for the arrangement of road surface. Reducing the need for imported materials, especially the most expensive and scarce ones, and improving the use of local materials and production waste has been and remains one of the most pressing problems of the road industry.

Many years of international and domestic practice indicate the possibility of using ash-slag waste as both road-building materials and starting products for their manufacture. Even in the USSR extensive research was conducted in the 70s and 80s of the last century and generalized methodological recommendations were developed to determine the rational distance of transportation of ash-slag waste in road construction depending on the design of road surface, composition of mixtures of road-building materials and new variants of construction, prices for materials, mode of transport for transportation [12]. They are based on the generalized results of the studies of the Soyuzdor NDI, GiprodorNDI, DerzhdorNDI and a number of other research organizations. The positive results of the use of ash slag in road construction are evidenced by the considerable number of publications from which the following conclusion can be made.

During the construction of roads, fly ash of dry selection is used as active hydraulic impurity together with cement or lime, as well as independent slowly hardening binder for placing layers of the basis and the cover from consolidated soil and waste obtained by crushing stone material.

Ash-slag mixtures are used as a material for the construction of embankments of earthen cover or inactive hydraulic additives in combination with cement in consolidation of soils on the roads of the III-IV categories.

All waste, depending on its composition, is divided into three groups: active, hidden active and inert. Within these groups they are distributed by the form of calcium oxide content: total, free, bound in sulfates and that, which is a part of clinker materials.

The first group of classified materials includes the materials, which are characterized by a total content of calcium oxide from 20 to 60 % and to 30 % of free calcium. This ash-slag has the properties of self-hardening and can be used as a separate binding material.

The second group includes ash-slag mixtures with the general content of calcium oxide from 5 to 20 % of free nitric calcium not more than 2 % and grounding module not more than 5. They are used as complex binding materials with activators.

Ash-slag mixtures, which are characterized by a high content of silicon and aluminium and low content of calcium and magnesium oxides, are included in the third group. Free oxides of calcium, which is an activator of curing process, can be completely absent in such mixtures and its maximum content does not exceed 1%. In this connection, such mixtures are primarily used as inert material (technogenic soils).

Only ash of dry selection has self-curing ability. It is called a slow self-curing binder.

The materials of the second group (hidden active) can be used for the same purposes together with cement or as an additive to cement (to save it).

With regard to the most common third group (inert), they can be used as an anthropogenic soil for the construction of earthen cover, as well as for the installation of foundations or in a mixture with cement-consolidated sand mixtures. Studies have shown that these materials, including dry trapping ash, cannot be independent binders when arranging the substrate layers from consolidated soils. However, hydraulic activity can be found in the mixtures with cement or sand and cement during the curing process. From this point of view, they can be attributed to the materials of the second group, although they do not contain calcium oxide.

Data on the grain and chemical composition of dump ash-slag mixtures of hydraulic removal shows that their grain composition is heterogeneous. By chemical composition such mixtures are inert. They contain mainly silicon, aluminium and iron oxides, and the content of calcium and magnesium oxides is so small that the grounding module does not exceed 0.21. This allows us to consider such mixtures as technogenic soils.

Thus, the domestic and foreign experience of using ash-slag mixtures in road construction indicates the following directions:

Dry Selection Ash:

– slowly self-curing binder for the arrangement of the basis layers of the road cover made of consolidated soils and stone materials;

– active hydraulic additive in combination with inorganic binders (cement or lime) for the arrangement of the basis layers;

– active hydraulic additive in combination with bitumen or polymer binders;

– additive instead of a part of cement and aggregate in the preparation of concrete and mortars.

Dump ash-slag mixtures of hydraulic removal:

– anthropogenic soil for the arrangement of road embankments;

– material consolidated with cement or other binders for the arrangement of the basis layers and additional layers of the basis of the road cover structure;

– inactive hydraulic additive to lime for the preparation of ash and lime binders in the consolidation of soil and stone materials;

– component of mineral powder or for its replacement and partially sand in the preparation of bituminous mineral mixtures;

– aggregate for the production of sand concrete.

The above information testifies to the sufficiently complete research and development conducted earlier and their testing for the possibility of widespread use of ash-slag waste in road construction. However, in the last three decades, they have hardly been applied in Ukraine. This was largely due to a significant reduction in the financing of the road industry, the lack of construction of new roads and an outdated legal framework that does not meet the new conditions of management.

2.1 Possibilities to increase the efficiency of thermal power plants waste utilization in the present conditions

At the present stage of development of the Ukrainian economy, within the framework of the implementation of the previously adopted program on the integration of the national transport system into the transport system of Europe, and after the adoption of the relevant laws on the creation of a specialized Road Fund, the State Targeted Economic Program for the Development of Public Roads of Public Importance for 2018–2022 (Target Program) was developed and adopted. All this and the implementation of the decentralization reform created improved financing conditions for the reconstruction and development of the country's road network and set the task of rational use of resources provided for road construction, including the use of local materials and industrial waste. Therefore, such circumstances directly created favourable conditions for the possibility of improving the efficiency of waste thermal power plants in road construction. In this case, it is advisable for the relevant ministries, departments and organizations, taking into account the best foreign experience, applying appropriate preferences for contracting organizations, to develop specific plans for the use of ash-slag waste both in the implementation of the Target Program and in the fulfilment of other tasks of restoration and development of the road network. In this regard, the urgent task is to improve the existing and develop new regulatory and technical documentation that will regulate the successful use of ash-slag in road construction. This will allow project organizations to anticipate technical solutions using TPP waste on specific highways.

Nowadays a number of current regulatory documents in a certain way regulate the possibility of using ash-slag waste in road construction.

Thus, in the construction of the road cover, it is necessary to comply with the requirements of Standard DBN V.2.3–4 [14], which provide for the use of soils according to the classification corresponding to NSSU (State standard) B.V.2.1–2 [15]. According to this classification, ash-slag mixtures of TPPs belong to class IV – technogenic dispersed soils, type – wastes of industrial and economic activity, species – ash-slag. It should be noted that ash-slag mixtures of TPP can be used both independently and as granulometric impurities to soil to optimize its grain composition. This provides opportunities for each object to use ash-slag mixture after the installation of technological and physical and mechanical characteristics, optimum moisture content, soil skeleton maximum density, porosity, true density, filtering ratio, strength characteristics (internal friction angle, specific adhesion), deformation characteristics (modulus of elasticity, modulus of deformation, coefficient of lateral deformation) and others.

When arranging the layers of the road structure from soils, consolidated with binding materials, it is necessary that ash-slag mixtures of TPPs meet the requirements of VBN V. 2.3-218-541 [16]. In addition, ash-slag mixtures can also be used as a component of a slag-alkaline binder when consolidating soils to replace traditional Portland cement, subject to the appropriate design and recipe selection of such materials [19].

When meeting the requirements of NSSU (State standard) B. V. 2.7-29 [17] and NSSU (State standard) B.V. 2.7-74 [18], small and large aggregates from industrial wastes, TPP ash-slag mixtures can be applied as small aggregates and large aggregates in various solutions and mixtures in general-construction and road use. In particular, in the manufacture of concrete mixtures in accordance with the requirements of NSSU (State standard) B. V. 2.7-211, as well as the arrangement of unpaved and reinforced crushed stone and gravel layers of the basis of the road cover in accordance with NSSU (State standard) B.V. 2.3-39: 2016 [21]. In addition, as components of binding ash-slag mixtures can also be used in the manufacture of lime cement in replacement of traditional Portland cement. For this purpose, all the necessary standard procedures for designing and selecting the recipes of the above materials should be carried out performing the necessary laboratory tests.

Ash-slag mixtures of thermal power plants can also be applied as mineral components of bitumen-mineral mixtures, both cold and hot, in compliance with the requirements of NSSU (State standard) B. V. 2.7-305: 2015 [22]. Such bituminous-mineral mixtures can be used both in the arrangement of the layers of the basic and surface layers of local roads during their construction and reconstruction, as well as major and current repair of public roads in all road-climatic zones of Ukraine in accordance with DBN B.2.3- 4 [14].

Subject to the requirements of SOU 42.1-37641918-104 [23], fly ash and mixtures of ash-slag thermal power plants can be applied to such types of work.

Depending on the type, ash can be used to prepare cement-concrete mixtures for the basis of rigid-type road construction and for cement-sand and gravel-sand mixtures consolidated with cement.

Ash-slag mixtures of group I are intended for the arrangement of additional layers of the basis of road cover (drainage and frost-protective layers), as well as a component of gravel-sand mixture or soil mixture. Ash-slag mixtures of this group, reinforced with inorganic binders, are suitable for the construction of the basis of road surface.

Ash slag mixtures of Group II may be used for the construction of foundations only with the addition of not less than 50 % crushed stone or after their hardening with inorganic binders.

Ash slag mixtures of Group III can be used in combination with lime or cement to strengthen coarse-grained mixtures or loose soils.

Ash slag mixtures of Groups I-III can be used for the construction of embankments of earthen cover according to DBN B.2.3-4 [1 4], DSTU-N B B.2.3-32: 2016 [24].

However, it should be noted that the above regulatory documents are mostly framework and general in nature. At the same time, ash-slag wastes at different TPPs differ significantly in chemical and mineralogical compositions, dispersion (from fine ash to coarse gravel) and other parameters. Therefore, it is advisable, on the basis of additional research, to develop technical documentation for the development of existing framework standards in order to make more efficient use of ash-slag for the production of road-building materials when constructing roads and streets. For example, when carrying out widespread types of work such as pit repair, especially in adverse weather conditions, in accordance with NSSU (State standard) C.3.2-5: 2016 [25], as well as when performing works on the alignment of the highway basis with cold method recycling in accordance with VBN B.2.3-218-539 [26] and other work, where the specific regulatory application of more specific use of ash and slag waste is not yet provided by the applicable regulations. Thus, for the utilization and use of ash-slag wastes from the Darnytsia CHP (Kyiv), based on the current norms for scientific and technical support of the construction facilities [27], SE “NDIBMV” together with NTU were developed TU U.2.7-08.12.13- 37739041-001: 2016 “Mixtures of ash-slag for backfilling and site planning”. For the same purpose, NTU conducted research and developed recipes for bitumen-mineral materials for pit repair.

3. Results and discussion on the development of bitumen-mineral materials recipes for pit repair of the road surface using ash-slag mixtures of Kyiv Darnytsa CHP

3.1. Materials for experimental studies

Ash-slag mixture

For the experiments, bitumen-mineral mixtures were made using the mineral part in the form of ash-slag mixtures of the Darnytsia CHP. Samples of ash-slag mixture for the experimental work were selected at the ash dump in Kyiv. The grain composition was determined from the average sample of the ash-slag mixture, from which it follows that it contains 27.9 % of crushed stone fraction of 5–10 mm, 55.6 % of sand and 16.5 % of mineral powder (according to the classification of the mineral part by the grain size [22]).

Organic binder

Viscous bitumen of the BND 60/90 brand of the Mozyr refinery was used as a binder for the production of hot mixtures, which meets the requirements of DSTU 4044. Liquid bitumen of the SG 70/ 130 brand was used to prepare cold mixtures, which meets the requirements of GOST 11955. Liquid bitumen of SG 70/130 brand was produced by mixing BND 60/90 bitumen of Mozyr refinery and 18 % of diesel fuel by weight of bitumen. Conditional viscosity at +60 C was 105 s.

Additives

Water repellents of a new generation system "Hydro" were used as additives, which provide a chemical bond with the surface of mineral materials.

3.2. Designing of bitumen-mineral material recipes based on ash-slag mixtures for pit repair

To test the possibility of using ash-slag mixtures which can be used for pit repair, the most common types and types of bitumen-mineral mixtures were considered. Hot fine-grained mixtures were made with granulometry of V and B types with the addition of granite crushed stone to create a framework on viscous BND 60/90 bitumen. Cold fine-grained mixtures were also made on the liquid bitumen of the SG 70/130 brand. Considering that the ash-slag mixture has a sufficiently large particle content of less than 0.071 mm, which leads to overconsumption of the scarce and the most expensive component in bitumen-mineral mixtures – bitumen, experimental studies have been carried out to reduce the content of such a finely dispersed component in order to save the bitumen binder.

For this purpose, they were completely screened and added according to the recipes in a reduced amount. From the mixtures of different formulations, standard laboratory samples were made and standard physico-mechanical characteristics were determined according to the results of their testing. The obtained results confirmed the possibility of reducing the cost of bitumen binder and ensuring the water resistance of organo-mineral concretes, respectively, due to the directional control of the number of fine-dispersed particles and the use of waterproofing agents. The conducted researches have allowed developing variants of recipes of different durability and cost for practical application on roads and streets of different categories with different traffic intensity. Examples of recipes for hot mixes are shown below (the amount of bitumen and hydrophobic additives are given in percent over 100 % of the mineral portion).

Option 1.1
Crushed stone granite fractions 5–10 mm – 18 %;
Ashtray ordinary – 82 %;
BND bitumen 60/90 – 7 %.
Option 2.3
Crushed stone granite fractions 5–10 mm – 18 %;
Ash-tree slag modified – 82 %;
GNI bitumen 60/90 – 6.4 %.

Option 3.2
Crushed stone granite fractions 5–10 mm – 18 %;
Ash-tree slag homogenized – 82 %;
GNI bitumen 60/90 – 6.1 %;
Hydrophobic impurities – 1 %;
PAR - 0.3 % of the amount of bitumen.

Option 4.1
Crushed stone granite fractions 5–10 mm – 42 %;
Ashtray ordinary – 58 %;
BND 60/90 bitumen – 6.3 %.

Option 5.2
Crushed stone granite fractions 5–10 mm – 42 %;
Ash-tree slag homogenized – 58 %;
GNI bitumen 60/90 – 5.8 %.

Option 6.1
Crushed stone granite fractions 5–10 mm – 42 %;
Ashtray ordinary – 58 %;
GNI bitumen 60/90 – 5.5 %;
Hydrophobic impurities – 1 %;
PAR – 0.3 % of the amount of bitumen.
Discussing the results we can state the following.

The grain composition of the ash-slag mixture of the Darnytsia CHP allows designing the optimum granulometry of bitumen-mineral mixtures. The possibility of directional control of the properties of bitumen-mineral materials of different durability and reduction of the cost of scarce bitumen binder is shown. The obtained results indicate the possibility and feasibility of using bitumen-mineral materials for pit repair both under favourable and unfavourable weather conditions on roads and streets of different categories, in different layers of road surface structures (covering, base, additional base) according to the current normative documents

Conclusion

Ash and slag waste of thermal power plants, which has already been accumulated and will be generated in considerable amounts, polluting the environment and occupying large territories of fertile land, is the conditioning material for the road industry in the construction, reconstruction, repair and maintenance of highways and streets, in construction and arrangement of the layers of the road basis and the cover, as well as in other types of work. To improve the efficiency of its use in road construction, along with other well-known measures, it is advisable to make an inventory of the ash and slag waste of each ash dump and develop technical conditions of its use and other technical documentation for wide use (process maps, typical albums of road construction designs, etc.)

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