USE OF SLAG MATERIALS IN ROAD CONSTRUCTION

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Abstract

In the design of the pavement layers of the base have the greatest thickness. Therefore, their construction is associated with a high consumption of building materials. At the same time, the base layers work in more favorable conditions when compared with coatings, which makes it possible to widely use local materials and industrial waste for their construction. The feasibility of their use is justified by technical and economic calculations, taking into account the possible reduction of the service life of the pavement as a result of the rejection of the use of standard imported materials. One of the most widely known types of waste used in road construction is slags from ferrous and non-ferrous metallurgy and phosphorus production. Their disposal is an important source of high-quality materials for road construction. Slag is a valuable raw material for the preparation of non-metallic materials and mineral binders. Active slags partially replace traditional binders (cement, lime) during the construction of road foundations and coatings. Long-term experience of road organizations shows that the cost of slag road-building materials is two times lower than the cost of similar products from natural rocks.

Keywords: slag; metallurgy; road clothing; construction; pavement; base layer, building

1. Introduction

According to statistics, there are, 8.6 billion cubic meters (23-25 billion tons) of industrial waste products in Ukraine located on the territory of 50 thousand hectares. Each year their amount only increases due to insufficient rates of processing (about 0.1-0.12 billion m3 annually). A significant share in the accumulation of solid industrial waste is produced by the metallurgical industry.

According to reports, 52 types of different waste products are formed in the process of manufacturing steel at enterprises. Regardless of the tendency to reorganization and restructuring of the industry (the share of oxygen-converted steel and electric steel in the total production volume is increased due to the decrease in the share of open-hearth production, i.e., work is performed to reduce the slag and sludge production), they are accumulated in dumps. Thus, on the one hand, there is a constant accumulation of solid industrial waste products and, on the other hand, there is a permanent shortage of mineral raw materials for road construction works.

This necessitates the implementation of programs related to the disposal of solid industrial waste dumps.

2. Discussion

2.1. The problem of using of slag materials

The problems of using metallurgical slags (both blast-furnace and open-hearth) in road construction attracted many experts [1-4]. It should also be noted that at present there have been developed and acting in Ukraine: the Law of Ukraine "On approval of the National Program for the Development of Ukraine's Mineral Resource Base for the Period up to 2030", State Target Scientific and Technical Program for the Development and Reforming the Mining and Metallurgical Complex of Ukraine for the Period up to 2020; regional energy conservation and development programs; regional environmental protection programs, etc. All these studies and legislative and regulatory acts take into account, to a certain extent, the issues of utilization of solid industrial waste, including the dump metallurgical slag.
Donetsk region has a historically established developed metallurgical industry, whose enterprises are well-known both in Ukraine and abroad. They are the following: PJSC "Azovstal Iron & Steel Works", PJSC "MMK named after Ilyich", PJSC "Donetskstal" (DMZ) and others. Only in the city of Mariupol about 40 million tons of slag, including both blast-furnace and open-hearth have been accumulated. Open hearth slag formed in open-hearth furnaces amount to 0.22 - 0.55 tons per ton of steel manufactured.

The utilization of open-hearth slag is limited to the use in the agrarian sector and as flux in blast furnaces. Open-hearth slag application in the construction industry is not productive: - open-hearth slag contains no less than 80% of calcium carbonate in the form of calcium and magnesium silicates. It also contains phosphorus, manganese, silicon dioxide, iron oxide, calcium carbide and the like; in the open-hearth slag there are residues of metal (up to 15%), including those in the form of scrap (up to 7%) and in the form of small particles (up to 8%). The average granulometric composition of the open-hearth slag is:
- 0-10 mm fraction - 22.6%;
- 10-60 mm fraction - 27.3%;
- 60-250 mm fraction - 30.18%;
- more than 250 mm fraction - 19.9%.

In the metallurgical industry, in order to improve the situation with the raw material (metal scrap), there are known methods of extracting metal from the dump slag (in this case, the metal is cast iron or steel remaining at the bottom of the ladle with slag). The slag is poured into the dump together with metal contained in the ladle under the slag layer. As it is not possible to pour out metal and slag separately when releasing the blast furnace, electric furnace or open-hearth furnace, metal is deposited at the bottom of the ladle with slag. The slag is poured into the dump together with metal contained in the ladle under the slag layer. As it is not possible to pour out metal and slag separately when releasing the blast furnace, electric furnace or open-hearth furnace, metal is deposited at the bottom of the ladle with slag. During transportation to the dump, the metal is settled at the bottom of the bucket and crystallized. A large flat piece of metal is formed at the bottom of the bucket. Usually the size of a piece is 0.8-1.4 meters in the diameter and 0.15-0.35 meter thick. Such pieces (in metallurgy referred to as "metal cakes") in glass dumps are blown together with slag. Therefore, the loss of metal with dump slag is 27% or more and the total loss of metal is over 30%.

2.2. Main stages of slag materials processing

Thus, in slag processing one should take into account the features of the material. At the first stage, metal cakes are isolated by scattering the dump slag in the drum, thus obtaining two products: metal cakes and slag. At the second stage, the slags rinsed with water, producing two products: flushed slag (large pieces) and silicon oxide and calcium carbonate formed as a result of natural decomposition of slag components into silicon oxide and calcium carbonate. These reactions can be represented schematically as:

\[ \text{CaO} \cdot \text{SiO}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{SiO}_2 \]

Slag is mainly mono-calcium silicate, di-calcium silicate, tri-calcium silicate. In the dumps, the following decomposition reactions of di- and tri-calcium silicates slag occur:

\[ 3\text{CaO} \cdot \text{SiO}_2 \rightarrow 2\text{CaO} \cdot \text{SiO}_2 + \text{CaO} \]

\[ \text{CaO} \cdot \text{SiO}_2 \rightarrow \text{CaO} \cdot \text{SiO} + \text{CaO} \]

\[ \text{CaO} \rightarrow \text{SiO}_2 \rightarrow \text{CaO} + \text{SiO}_2 \]

Calcium oxide reacts with atmospheric carbon dioxide to form calcium carbonates

\[ \text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3 \]

According to the normative requirements, solid particles of silicon oxide and calcium carbonate should be extracted from slag and used for clinker production. At the next stage iron particles are obtained from the flushed slag by magnetic enrichment, which are then used for steel smelting in electric or open-hearth furnaces. The next step is grinding of slag in rotary crushers with magnetic enrichment, thereby releasing oxide iron which is also directed for remelting. At the last stage, the slags separated into two products: slag chips (5-30 mm fractions) and slag sand (less than 5 mm fraction).

Organic-mineral substances including both organic binders (providing ligament and elasticity of the system) and mineral (capable to hydrate binders), are characterized by coagulation and crystallization bonds. The ratio of coagulation and crystallization contacts causes the deformation-strength characteristics of such a composite material [1, 2, 5].

The analysis of the results of industrial implementation shows that metallurgical slags is an effective substitute for natural stone materials used for construction and repair of highways. As a rule, metallurgical slags not inferior in its properties to materials obtained from natural hard rock, and sometimes even surpasses it. And this is despite the fact that the use of metallurgical slag, in general, reduces the cost of road pavement construction by
14-15% as compared with similar designs of granite materials [5-6].

Taking into account their physical and mechanical properties, slag crushed stone, sand and their mixtures are used for all types of structural road layers: pavements, bases, additional layers of the base, etc. And, a promising use of ferrous metallurgy slag for strengthening soils when laying road bases is observed as well.

The experience of road construction shows that sufficiently strong road foundations are obtained from a mixture of crushed stone of active slag and weak limestone. Chips of open-hearth slag are successfully used to wedge road bases made of crushed granite. When laying the road base, slag crushed stone has advantages over granite one. Due to greater surface roughness of the grains it is easier to roll. If we take the time needed to roll the road base layer of crushed granite as a unit, then the time for rolling the layer of slag chips of the same thickness will be 0.63-0.72. And, the base of slag crushed stone is more durable. Slag crushed rock contains a certain amount of grit which increases significantly at rolling during roadbed construction.

Powder-like steel-smelting and blast-furnace slag is a low-grade binder and can form a monolithic road base, the strength of which is significantly increased by adding even a little amount of cement and lime as an activator. Slag sand is used for the production of asphalt concrete and as an active mineral additive. Depending on its size, the fractionated slag crushed stone is used for upper and lower base layers of the I-V category roads by wedging. Crushed stone blends of 0-20 (40) mm fraction active slag serve as a loosening material. 10-20 mm fraction slag treated with organic binder materials is also used when laying the upper and lower layers of III-V category road pavements.

Crushed-stone mixtures of 0-70 (120) mm fraction active and high-level slag of optimal grain composition are used for placing the upper and lower layers of semi-rigid I-V category road bases.

Crushed-stone mixtures of low-level slag are activated using CaCl_2, Na_2CO_3, CaSO_4. The feature of asphalt concrete pavements obtained with the use of steel-smelting slag is the absence of shearing strain, even under intense heavy vehicle traffic. Slag sand and powder play the role of the main binder in slag crushed-stone mixtures.

At the initial stage of road operation, the semi-rigid base of active slag works as a material, the bearing capacity of which is provided by the skeleton density and crushed stone fractions wedging. Such bases do not cause subsidence and have an increased elasticity modulus of 300-400 MPa. In the process of operation, they are transformed into a monolithic stable plate. The elasticity modulus of semi-rigid bases increases to 1200 MPa.

Depending on the strength and durability requirements, one-or two-layers slag bases are used. The maximum thickness of the layer is up to 20 cm with material size up to 110 mm and - up to 16 cm with material size up to 70 mm. The lowest thickness of the layer is set calculating the largest fraction size to be not more than 0.7-0.75 of the layer thickness. Materials made of cement, slag and soil, used for various designs of road pavement base layers [6-7] have a rather high strength (1.4-8.2 MPa), water resistance (0.96-1.17) and frost resistance (0.71-8.22).

The long-lasting nature of strengthening materials indicates their durability. This conclusion based on laboratory experiments fully corresponds to the results of studying the elasticity modulus of the road pavement structures in experimental areas. For 2 years of operation, the actual total elasticity modulus (153-330 MPa) of road pavements significantly exceeded its design value (138 MPa).

In accordance with the requirements of regulatory documents, slag and ash slag having grain composition of 0-40 mm, strength of 300 kgf/cm², frost resistance of MRZ 25 can be used in road construction. Ash can be used as mineral powder. In this case, the ash should contain at least 45% of the particles smaller than 0.071 mm. A prerequisite for obtaining high-quality organic-mineral mixtures is high adhesion of organic binder to the surface of mineral materials. In this regard, it is expedient to use anionic emulsions [8-9] to manufacture organic-mineral mixtures on the basis of open-hearth slag chip [8-9], since the potentiometric ion of open-hearth furnace slag particles is a Ca^2+ cation. Besides, it is advisable to modify the slag surface with unslaked ground lime (CaO) to accelerate the decay rate of the bituminous emulsion, while the dispersed phase of anionic emulsions has a negative charge.

A wide range of emulsifiers for the production of anionic bituminous emulsions is presented in the Ukrainian market, the main ones being: A-2 grade asidol of the mark (GOST 13302-27 *); axidol-myronaph (GOST 13302-77 *); myronaph (GOST...
13302-77 *); synthetic fatty acids (cub balance) (OST 38,01116-76); oxidized petroleum (TU 38-301-96-83); sulfate cute, gray (TU 81-05-118-77); cute cheese (OST 13,184-83E); second fat tar (OSTU 360-9121-63); gossipol resin (cub balance); woodtarresin (TU 81-05-2-78); fat mass (TU 18UzSSR45-81); Thaw Peck (TU 81-05-84-80); pitch thawed bleached brand B (OST 13- 145-82); AZOL 1018 (TU 2490-035-00205-423-2007); doros-EmA (TU 2482-026- 33452160-2012), etc.

In order to improve the quality of open-hearth slag organic-mineral mixtures with the use of anionic bituminous emulsion, it is recommended to use alkaline activators –usually lime and portland cement. Ca(OH)$_2$ water solution formed both during lime hydration and the hydrolysis of cement clinker minerals, allows to create alkaline medium with a sufficiently high p$H$ in an organic-mineral mixture, which provides slagdispersion due to the breakdown of covalent Si-O-Si and Al-O-Si bonds as a result of increasing the gateway environment ionic force by introducing ions with high electrodonor properties into its composition.

3. Conclusion

Thus, the production of open-hearth slag organic-mineral mixtures will allow not only to implement the program for solid industrial waste utilization but to extend the possibility of performing repair and restoration operations on Ukraine roads as well.

References


В конструкції дорожнього одягу шари основи мають найбільшу товщину. Тому їх будівництво супроводжується великою витратою будівельних матеріалів. В той час основи працюють в більш сприятливих умовах порівняно з покриттями, що дозволяє широко використовувати для їх будівництва місцеві матеріали і відходи виробництва. Доцільність їх використання обґрунтовують техніко-економічними розрахунками урівнювання можливого зменшення строку служби дорожнього одягу в результаті відмови від застосування стандартних привізних матеріалів. Одними з найбільш відомих видів відходів, які використовуються в дорожньому будівництві, є шлаки красної, кольорової металургії і фосфорного виробництва. Їх утилізація є важливим джерелом отримання високоякісних матеріалів для дорожнього будівництва. Шлаки використовуються для приготування нерудних матеріалів і мінеральних в'яжучих. Активні шлаки частково заминають традиційні в'яжучі (цемент, вапно) при будівництві дорожніх основ і покриттів. Багаторічний досвід дорожніх організацій показує, що використання шлакових дорожньо-будівельних матеріалів в два рази нижче собівартості аналогічної продукції з природних гірських порід.

Ключові слова: шлак; металургія; дорожній одяг; конструкція; покриття; шар основи; будівництво

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Использование шлаков в дорожных конструкциях

Ключевые слова: шлак; металлургия; дорожная одежда; конструкция; покрытие; слой основания; строительство

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