

UDC 625.7

DOI: 10.18372/2306-1472.77.13502

**Kateryna Krayushkina¹,
Tetiana Khimerik²,
Valerii Pershakov³,
Andrii Bieliatynskiy⁴**

USE OF SLAG MATERIALS IN ROAD CONSTRUCTION

¹National Aviation University, 1, Kosmonavta Komarova ave., 03058, Kyiv, Ukraine
E-mails: ¹ekrayushkina15@ukr.net; ²khimerik@ukr.net; ³pershakov@nau.edu.ua;
⁴beljatynskij@ukr.net

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.

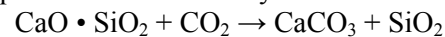
It also contains phosphorus, manganese, silicon dioxide, iron oxide, calcium carbide and the like; in the open-hearth slag there are residues of metal (up to 15%), including those in the form of scrap (up to 7%) and in the form of small particles (up to 8%). The average granulometric composition of the 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%.

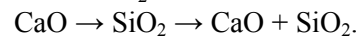
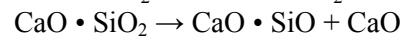
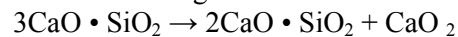
In the metallurgical industry, in order to improve the situation with the raw material (metal scrap), there are known methods of extracting metal from the dump slag (in this case, the metal is cast iron or steel remaining at the bottom of the ladle with slag). The slag is poured into the dump together 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 ladle bottom 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 of 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

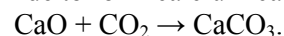
Thus, in slag processing one should take into account the features of the material. At the first stage, metal cakes are isolated by scattering the dump slag in the drum, thus obtaining two products: metal cakes and slag. At the second stage, the slag is rinsed with water, producing two products: flushed 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:



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 occur:



Calcium oxide reacts with atmospheric carbon dioxide to form calcium carbonates



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 slag is 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 slag 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 low-grade binder and can form a monolithic road base, the strength of which is significantly increased by way of 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-layer 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 (0,71-822).

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 pavement 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 groundlime (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-mylnapht (GOST 13302-77 *); mylnapht (GOST

13302-77 *); synthetic fatty acids (cube balance) (OST 38,01182-82 Brand B); Petrov's contact (OST 38,01116-76); oxidized petrolatum (TU 38-301-96-83); sulfate cete, gray (TU 81-05-118-77); cete cheese (OST 13,184-83E); second fat tar (OSTU 360-9121-63); gossipol resin (cube 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. $\text{Ca}(\text{OH})_2$ water solution formed both during lime hydration and the hydrolysis of cement clinker minerals, allows to create an alkaline medium with a sufficiently high pH in an organic-mineral mixture, which provides slag dispersion 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

[1] Bratchun V.I. O nekotorykh osobennostyakh formyrovaniya struktury vlazhnykh dehteshlakobetonov / Some peculiarities of structure formation wet tarslag concrete / V.I. Bratchun, A.N. Bachurin // Collection of scientific papers «Using the waste industry for the production of building materials». - K. : UMK BO, 1990. - P. 14-22.

[2] Bratchun V.I. Modyfytsirovannyye dehty y dehtebetonovy povyshennoy dolhovechnosty / Modified tars and tarmacadam enhanced durability / V.I. Bratchun, V.A. Zolotarev - Makiyvka, 1998 - 226 p.

[3] Bratchun V.I. Yzuchenye osobennostey hydratatsyy otval'noho martenovskoho shlaka / Study of the features of dump hydration of the open-hearth slag / V.I. Bratchun, V.A. Zolotarev,

V.A. Mimrin, V.N. Levchenko, A.N. Bachurin // Coll. Intern works Scientific and Technical Conference "Resource Saving and Ecology of the Industrial Region" // Saving technologies in the production of building materials. - vol. 1. - Makeevka: DonSACEA. - 1995 - p.25-29

[4] Samodurov S.I. Asphalt concrete for slag materials / S.I. Samodurov - Voronezh: Publishing House of the Voronezh State University, 1984. - 108 p.

[5] Goglidze V.M. Osnovy sovместnoy raboty materyalov s bytumnyy y tsementnyy vyazhushchymy v poluzhestkykh dorozhnykh pokrytyyakh / Through joint work with bituminous materials and cement binder in the semi-rigid pavements / V.M. Goglidze, M.Sh. Dzidziuri // Proceedings SoyuzDorNII. - M., 1971. - №4. - P.111-118

[6] Yadikina V.V. Povyshenye kachestva vlazhnykh orhanomyneral'nykh smesey / Improving the quality of organic wet mixtures / V.V. Yadikina, A.I. Morozov, V.I. Shuhov // Avtomobyl'ni dorohy. - 1992 - № 5-6. - P.19-20.

[7] Kuzmichev V.T. Ustroystvo poluzhestkykh sloev dorozhnykh odezhd yz metallurhycheskykh shlakov / Semi-rigid device pavement layers and slag / V.T. Kuzmichev, L.G. Lizhenko, L.M. Urman // Avtomobyl'ni dorohy. - 1986 - №5 - p. 56-57.

[8] Bratchun V.I. Poetapnaya optymyzatsyya sostavov asfal'toshlakobetonov, pryhotovlennykh na anyonnoy bytumnoy emul'syy / Gradual optimization formulations asfal'toshlakobetonov prepared anionic emulsion / V.I. Bratchun, Yu.V. Gritsuk // Proceedings of the 40th International Workshop on Modeling and Optimization of Composites "Simulation and Optimization in Materials Science." - Odessa: Astroprint, 2001. - P. 45-47.

[9] Bratchun V.I. Optymyzatsyya sostavov asfal'toshlakobetonov na anyonnoy bytumnoy emul'syy / Optimization of structure asfal'toshlakobetonov anionic emulsion / V.I. Bratchun, Yu.V. Gritsuk // Modern Problems of Construction / Annual Scientific and Technical Collection. - Donetsk: Donetsk PromstroyNIIproject, LLC "Lebed", 2000 - volume II. - P.5-9.

К.В. Краюшкіна¹, Т.Ю. Химерик², В.М. Першаков³, А.О. Белятинський⁴

Використання шлаків в дорожніх конструкціях

¹ДерждорНДІ, просп. Перемоги, 57, Київ, Україна

^{2,3,4} Національний Авіаційний Університет, просп. Космонавта Комарова, 1, Київ, 03058, Україна

E-mails: ¹ekrayushkina15@ukr.net; ²khimerik@ukr.net; ³pershakov@nau.edu.ua; ⁴beljatynskij@ukr.net

В конструкції дорожнього одягу шари основи мають найбільшу товщину. Тому їх будівництво супроводжується великою витратою будівельних матеріалів. В той же час шари 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 урахуванням 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 чорної, кольорової металургії і фосфорного виробництва. Їх утилізація є важливим джерелом отримання високоякісних матеріалів для дорожнього будівництва. Шлаки являють собою цінну сировину для приготування нерудних матеріалів і мінеральних в'язучих. Активні шлаки частково замінюють традиційні в'язучі (цемент, вапно) при будівництві дорожніх основ і покриттів. Багаторічний досвід дорожніх організацій показує, що собівартість 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

Е.В. Краюшкіна¹, Т.Ю. Химерик², В.Н. Першаков³, А.А. Белятинский⁴

Использование шлаков в дорожных конструкциях

¹ГосдорНИИ, пр-т Победы, 57, Киев, Украина

^{2,3,4} Национальный Авиационный Университет, просп. Космонавта Комарова, 1, Киев, 03058, Украина

E-mails: ¹ekrayushkina15@ukr.net; ²khimerik@ukr.net; ³pershakov@nau.edu.ua; ⁴beljatynskij@ukr.net

В конструкции дорожной одежды слои основания имеют наибольшую толщину. Поэтому их строительство сопряжено с большим расходом строительных материалов. В то же время слои оснований работают в более благоприятных условиях при сравнении с покрытиями, что позволяет широко использовать для их строительства местные материалы и отходы промышленности. Целесообразность их использования обосновывают технико-экономическими расчетами с учетом возможного уменьшения срока службы дорожной одежды в результате отказа от применения стандартных привозных материалов. Одними из наиболее широко известных видов отходов, которые используются в дорожном строительстве, являются шлаки черной, цветной металлургии и фосфорного производства. Их утилизация является важным источником получения высококачественных материалов для дорожного строительства. Шлаки представляют собой ценное сырье для приготовления нерудных материалов и минеральных вяжущих. Активные шлаки частично заменяют традиционные вяжущие (цемент, известь) при строительстве дорожных оснований и покрытий. Многолетний опыт дорожных организаций показывает, что себестоимость шлаковых дорожно-строительных материалов в два раза ниже себестоимости аналогичной продукции из естественных горных пород.

Ключевые слова: шлак; металургія; дорожная одежда; конструкція; покрытие; слой основания; строительство

Krayushkina Kateryna. Candidate of technical sciences, Doctor of science in technology, Head of the department of modern road works technologies State road scientific research institute named MP Shulgina.

E-mail: ekrayushkina15@ukr.net

Khimerik Tetiana. Candidate of technical sciences, senior research fellow, Associate Professor of the Department of Reconstruction of Airports and Roads of the Educational - Scientific Institute of Airports, National Aviation University.

E-mail: khimerik@ukr.net

Pershakov Valerii. Doctor of engineering, professor of the Department of reconstruction of airports and roads of the educational - scientific institute of airports, National Aviation University.

E-mail: pershakov@nau.edu.ua

Beliatynskiy Andrii. Doctor of engineering, Head of the Department of reconstruction of airports and roads of the educational - scientific institute of airports National Aviation University.

E-mail: beljatynskij@ukr.net