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Road slag asphalt concrete

Abstarct. *Asphalt and concrete road surfaces are an essential part of the infrastructure of transport systems, and in recent years slag road asphalt has gained popularity as an efficient and environmentally friendly alternative. Slag asphalt, produced by incorporating slag, a by-product of industrial steel production, into asphalt concrete mixes, is the subject of this review article. The article presents a review of researches papers on the use of slag road asphalt. This article reviews the composition, production and physical and mechanical characteristics of slag asphalt concrete. Particular attention is paid to studies of the effect of slag on the strength, fracture resistance and deformation of the material. The authors provide an overview of the various methods of modifying slag asphalt to improve its performance and durability of road surfaces. The article also highlights the environmental importance of slag asphalt, generalized its ability to reduce the use of natural resources and reduce waste from the steel industry. The overall analysis of these articles suggests the potential of using slag road asphalt concrete as an effective and environmentally sustainable material in road construction. However, further research and practical tests are needed to confirm its applicability in different climatic and road conditions. The final part of the article discusses the significance of slag asphalt concrete in the context of sustainable road construction. The potential of slag asphalt to save costs in the construction and maintenance of road infrastructure, as well as to improve its durability and sustainability, is emphasized. In conclusion, the article provides a generalised overview of slag asphalt concrete, its advantages and promising applications in road construction.*

Keywords: *asphalt concrete, steel slag, silica fume, road surfaces*

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Introduction

Roads are strategically, economically and socially crucial for our country. The condition of roads that do not comply with road traffic rules and regulatory and technical requirements slows down the movement of transport and increases the number of accidents on the roads. Currently, more than 70% of the public road network in Kazakhstan has hard asphalt concrete pavements, which in the process of operation can experience various disturbances and deformations.

There is a need for a new approach to solving the issues of pavement durability under the conditions of real dynamic impact of vehicles on road structures in connection with the constant growth of traffic intensity on motorways, increasing load capacity and axle load of vehicles, increasing traffic speeds.

Currently, the service life of road pavements does not meet the required service life. The load on vehicle axles has increased significantly in recent years, and asphalt concrete pavements made in compliance with standards are losing smoothness and are covered with a network of fatigue and temperature cracks, which accelerates their destruction.

The service life of asphalt concrete pavements today, which used to be 15-18 years, is more often 8-12 and sometimes 3-4 years, which requires significant additional costs for road repair and rehabilitation. Due to the expansion of the road network and the increase in road construction, material resources are in short supply. In this case, the possibility of increasing the strength of asphalt concrete pavements through the use of scarce, inexpensive production waste is an important task of road construction**.**

Research methods

There are several testing methods that are used to determine the characteristics of steel slag asphalt concrete. Physical tests measure density, water absorption, and other physical properties of the material. Mechanical tests are used to determine mechanical properties including resistance to wear, strength, and fatigue. Chemical analysis, microstructural analysis and thermal analysis are additional methods of investigation.

Researchers Zhao, Zenggang, Zipeng Wang, Shaopeng Wu, Jun Xie, Chao Yang, Na Li and Peide Cui used physical and mechanical testing in their experiments. They analysed characteristics such as moisture resistance, bending and strength and compared the results with Chinese standards, particularly GB/T 16899-2011: Testing methods for asphalt strength.

Researchers from the University of Jordan, including Naser, Mohammad, Mu'tasim Abdel-Jaber, Rawan Al-Shamayleh, Reem Ibrahim, Nawal Louzi and Tariq AlKhrissat, conducted similar studies. They used ASTM D1075, Standard Test Method for Effect of Water on Compressive Strength of Compacted Bituminous Mixtures.

Researchers Peter Mikhailenko, Zhengyin Piao and Lily D. Poulikakos from Yale University conducted mechanical tests to determine the elastic modulus of three materials at 10°C. Poulikakos from Yale University conducted mechanical tests to determine the modulus of elasticity of three materials at 10°C. The experiment was performed according to Technische Prüfvorschriften für Asphalt: Einaxialer Druckschwellversuch - Bestimmung des Verformungsverhaltens von Walzasphalt bei Wa¨rme, 2010. In addition, their study conducted a chemical analysis to assess the environmental impact. For this they referred to the Swiss standards SN 640-430c Walzasphalt: Konzeption, Ausführung und Anforderungen an die eingebauten Schichten, 2014 and SNR 640 436 Semidichtes Mischgut und Deckschichten Festlegungen, Anforderungen, Konzeption und Ausführung, 2015.

Thus, various research methods are used to characterise steel slag asphalt concrete, including physical and mechanical testing, chemical analysis and other methods.

Results and Discussion

In order to meet the needs of the road sector during the repair, construction and operation of the roadbed of motorways, it is necessary to reduce the cost of construction materials at this stage of work of a part of the construction industry. It is also desirable to improve technical and operational qualities of developed materials, as well as to reduce logistic and time costs. These requirements are met by slags - a by-product or secondary product of metallurgy, which includes both ferrous and non-ferrous metals (combustion products). Their use occurs throughout the construction process of the road component, including the creation of mineral aggregates, asphalt concrete, structural road concrete and, in some cases, even thermal insulation. It is therefore important to consider the use of heavy industrial waste and select the best recycled materials to improve the performance and durability of the road surface.

For road construction it is possible to use crushed stone of blast-furnace and steelmaking slags and aggregate slag materials of blast furnaces, slag and slag-pumice sands, domed and blast-furnace granulated slags, slag production waste.

Kazakhstan has accumulated over 30 billion tonnes of slag waste. The main amount of waste in the country today has been created by the mining and metallurgical industries - almost 20 billion tonnes, and from the ores in non-ferrous metallurgy are mainly extracted from the force of two to three percent of useful elements, and the remaining 97-98 percent go to the dump. These are so- called technogenic-mineral formations, which, being unnecessary after primary processing, remain in open pits.

As a solid industrial waste, steel slag has similar physical and mechanical properties to natural stone and has great potential to replace natural aggregate, [1-2]. However, the source, mechanical properties and expandability of steel slag directly affect its widespread use in asphalt pavement. Steel slag is usually used as a coarse ag g r e g a t e in asphalt pavement mixes, and it is not recommended to be replaced by fine aggregate or filler in a project. This is because steel slag has high hardness and poor grindability, and replacing steel slag with fine aggregate or filler will further increase asphalt consumption and risk reducing volume stability [3].

Nowadays in Kazakhstan there is an obvious need to save material resources of the country, to develop and master waste-free innovative technologies. In the nearby territories of Arcelor Mittal Temirtau JSC, $200 million was allocated. more than a tonne of waste was collected, which negatively affects the environmental situation not only in the city of Temirtau, but also outside the Karaganda region. In our country, the main part of blast furnace slag melt is granulated. As for steelmaking slag, the main part of it is poured into a mound, and only a small part of it is processed into crushed stone, fertiliser, slag.

The productivity of ArcelorMittal Temirtau JSC's metallurgical production is constantly growing, and the amount of slag produced is increasing accordingly. It is planned to increase slag output up to 900 thousand tonnes per year (blast furnace slag - up to 600 thousand tonnes per year, BOF slag - up to 300 thousand tonnes per year).

In 2020, ArcelorMittal Temirtau's slag pumice was processed into fractional crushed stone, producing about 210 thousand tonnes of slag sand. The volume weight of asphalt concrete pavement compacted on the basis of slag-pumice sand is 2.2 tonnes/m^3. At 9% of bitumen and using the entire output of slag-pumice sand for road purposes, it is possible to obtain 291 thousand tonnes of asphalt-concrete mixture sufficient to install 170 km of roadbed with a thickness of 9 cm.

Researchers Zhao, Zenggang, Zipeng Wang, Shaopeng Wu, Jun Xie, Chao Yang, Na Li and Peide Cui from Wuhan University of Technology, Tongji University and Southeast University in Nanjing, China, conducted a joint experiment comparing the performance of steel slag asphalt concrete and basalt asphalt concrete. [5]

Marshall stability test, indirect tensile test, dynamic stability test and beam bending test were conducted to evaluate the moisture susceptibility, high temperature performance and low temperature performance of the asphalt mixture in accordance with standard test methods for bitumen and bituminous mixtures for highway construction.

The test results showed that steel slag asphalt mix has higher Marshall moisture resistance than basalt mix. The stability of steel slag asphalt mix is 13.9 kN, while the basalt mix reaches 11.8 kN. In addition, the steel slag asphalt mix exhibits a tensile strength coefficient of 92.6% or higher, while the basalt mix achieves a value of 88.2%. Both values exceed the minimum requirements set by China Standard 2011, which are at least 80%. Thus, it can be concluded that steel slag asphalt mix has higher tensile strength compared to basalt asphalt mix.

In addition, a flexural tensile test was conducted. The results showed that steel slag asphalt mix has higher flexural tensile strength, better deformation and higher stiffness compared to basalt asphalt mix. Nowadays, flexural tensile strain is often used to evaluate the performance of asphalt at low temperatures. The greater the maximum flexural tensile strain, the better the low temperature deformation resistance of the asphalt mix and the more pronounced its resistance to cracking.

The flexural tensile strain values for steel slag asphalt mix and basalt asphalt mix are 3247.1 με and 3103.4 με, respectively, exceeding the specification requirement of 2800 με. Thus, the low temperature performance of the asphalt mix using steel slag as coarse aggregate is found to be better than that of the mix using basalt. This is due to the excellent adhesion between steel slag and asphalt as well as the good bonding effect between steel slag aggregates, table 1.

Table 1. The results of trabecular bending test

Types	Ultimate flexural tensile strength (MPa)	Ultimate flexural Tensile strain (με)	Stiffness modulus (MPa)
Steel slag asphalt mixture (ARHM-13)	10.726	3247.1	3303.3
Basalt asphalt mixture (ARHM-13)	10.148	3103.4	3270.0

This can be attributed to factors such as the high angularity index, the presence of many pores in the structure and the chemical composition of the steel slag aggregate. Due to these features, steel slag provides better adhesion to asphalt compared to basalt. However, it is worth noting that steel slag asphalt mix also has a higher susceptibility to moisture compared to basalt asphalt mix.[5].

All products of slag processing are economical. For example, slag gravel is 1.5-2 times cheaper than natural gravel and requires 4.5 times less investment in equity capital; slag pumice is 3 times cheaper than expanded clay and 1.5 times less investment in equity capital [5] and the use of 1 tonne of granulated slag in the cement industry increases cement output by 1 tonne, which costs 9 times less and requires 9 times less investment in equity capital.

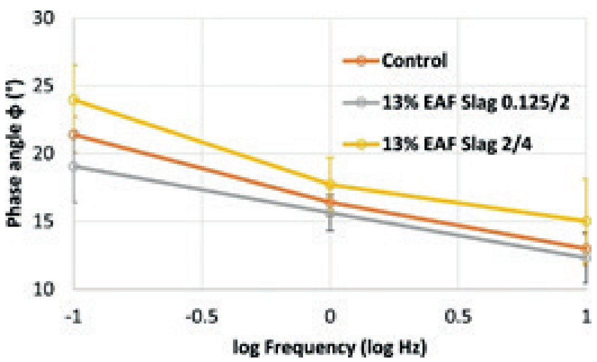
The University of Jordan conducted an interesting experiment in which researchers Naser, Mohammad, Mu'tasim Abdel-Jaber, Rawan Al-Shamayleh, Reem Ibrahim, Nawal Louzi and Tariq AlKhrissat participated. In this experiment, they conducted a number of studies in order to investigate certain aspects. This paper discusses the results of an experimental study conducted to evaluate the performance of recycled asphalt concrete mixtures made using reclaimed aggregate for asphalt pavements (RAP). These mixtures were also prepared using two aggregate additives, namely steel slag (SS) and silica fume (SF), in four different percentages by weight of aggregate. [6]

The Marshall stability and flowability tests were carried out in two stages. In the first stage, mixtures containing RAP materials with different asphalt contents were prepared to determine their optimum asphalt content (OAC); therefore, in the second stage, new RAP mixtures with appropriate OAC at different additive percentages were prepared and tested. The tests conducted in the first phase confirmed the effectiveness of RAP agglomerates as a replacement for natural aggregate in hot mix asphalt mixtures. The overall results showed that mixtures with RAP had more stable characteristics than those with limestone. The maximum stability values were achieved for mixtures containing 75% and 100% RAP when asphalt binder was added at a rate of 2%. This indicates that the use of RAP agglomerates can reduce the need for asphalt.

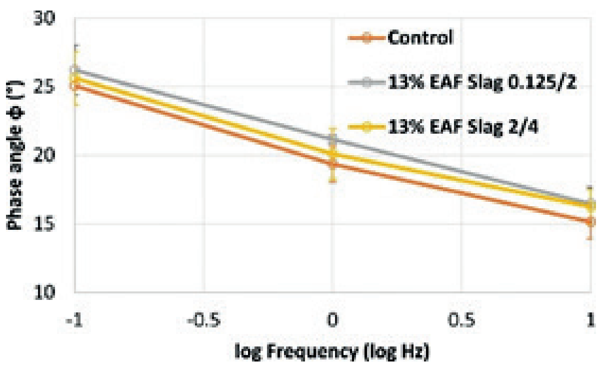
As shown in the test results, the addition of steel slag to RAP mixtures resulted in improved mechanical and volumetric properties of the asphalt mixtures due to the density of the steel slag. Marshall stability improved significantly for mixtures containing 50% and 75% RAP when 75% and 50% fine steel slag was added, respectively. The highest recorded load for stability was 32.73 kN for mixtures containing 75% RAP and 50% steel slag when 2% asphalt binder was added.[6]

Researchers Peter Mikhailenko, Zhengyin Piao, Lily D. Poulikakos from Yale University and the Swiss Graduate School of Technology in Zurich conducted an experiment investigating the possibility of using electric arc furnace slag as an aggregate in semi-dense asphalt, [7].

Several experiments were conducted as part of the study, including the determination of the Modulus of Stiffness. The results indicated that the control mixture had higher stiffness compared to the electric arc furnace slag mixtures. Although electric arc furnace slag was found to increase the stiffness, the discrepancy here may be due to the influence of the additional additive. In absolute terms, the elastic modulus values obtained for the three materials tested at 10◦C and 10 Hz, which are typical test parameters, were 9952, 7960, 7479 MPa, Figer 1, 2. These values are slightly lower than the elastic modulus values obtained for a similar mixture in the previous study, which were 10,231 MPa.



Figer 1. Phase angle (°) from stiffness modulus tests at 5 °C.



Figer 2. Phase angle (°) from stiffness modulus tests at 10 °C.

An experiment was also conducted to determine the environmental impact. The study showed that modified semi-dense asphalt containing electric arc furnace slag reduced greenhouse gas emissions and environmental negative contribution by 40% and 90%, respectively, compared to conventional semi-dense asphalt. The main factor behind these results is the avoidance of burial of electric arc furnace slag. However, the use of this material does not improve the non-renewable energy input potential.

Conclusions

The review article on slag concrete for highways provided important information on the use of slag as a sustainable substitute in road construction, so in conclusion. According to the findings of the article, the addition of slag to asphalt concrete can have a number of positive effects on performance, economic efficiency and environmental sustainability.

Firstly, the addition of slag to asphalt concrete improves the mechanical properties of the mix, such as its resistance to rutting, stiffness and fatigue. These improvements are attributed to the angular shape, high hardness and bonding properties of slag, which contribute to the bearing capacity and durability of road surfaces.

Secondly, the use of slag in road construction helps to preserve the environment. The article emphasizes the reduction of resource consumption and dependence on quarries by replacing some of the traditional aggregates with slag. The use of slag also reduces industrial waste and helps in recycling and reusing industrial by-products. This strategy encourages a circular economy and is in line with sustainable development goals.

In addition, there are obviously financial advantages to adding slag to asphalt concrete. Slag is often readily available as a by-product of various industries, such as steel production, and its use can lead to cost savings in road construction. Reduced reliance on virgin aggregates can reduce material costs, and the improved performance and durability of slag concrete for highways can lead to longer service life and reduced maintenance requirements, resulting in significant cost savings over time.

Overall, the findings of this review article emphasize the potential of slag concrete as a sustainable and cost-effective solution in road construction. Slag utilization provides increased productivity, environmental and economic benefits. Further research and field studies are needed to address the remaining challenges and to ensure the successful implementation of slag-based asphalt concrete in practice.

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Шлаковый дорожный асфальтобетон

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Абстракт. Асфальтовые и бетонные дорожные покрытия являются неотъемлемой частью инфраструктуры транспортных систем, а в последние годы шлаковый дорожный асфальт приобрел популярность как эффективная и экологически чистая альтернатива. Предметом данной обзорной статьи является шлаковый асфальт, полученный путем включения шлака, побочного продукта промышленного производства стали в асфальтобетонные смеси. В статье представлен обзор последних научных работ по использованию шлакового дорожного асфальта. В данной статье рассмотрены состав, технологические и физико-механические характеристики шлакоасфальтобетона. Особое внимание уделяется исследованиям влияния шлака на прочность, сопротивление разрушению и деформацию материала. Авторы представляют обзор различных методов модификации шлакового асфальта для улучшения его характеристик и долговечности дорожных покрытий. В статье также подчеркивается экологическое значение шлакового асфальтобетона. Общий анализ этих статей свидетельствует о возможности использования шлакового дорожного асфальтобетона в качестве эффективного и экологически устойчивого материала в дорожном строительстве. Однако необходимы дальнейшие исследования и практические испытания для подтверждения его применимости в различных климатических и дорожных условиях. В заключительной части статьи рассматривается значение шлакоасфальтобетона в контексте устойчивого дорожного строительства. Подчеркивается потенциал шлакового асфальта для экономии затрат при строительстве и содержании дорожной инфраструктуры, а также для повышения ее долговечности и устойчивости. В заключение в статье дается обобщенный обзор шлакоасфальтобетона, его преимуществ и перспектив применения в дорожном строительстве.

Ключевые слова: асфальтобетон, стальной шлак, микрокремнезем, дорожные покрытия

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Аңдатпа. Асфальтты және бетонды жабындар көлік жүйелері инфрақұрылымының құрамдас бөлігі болып табылады және соңғы жылдары шлак жол асфальты тиімді және экологиялық таза балама ретінде танымал болды. Осы шолу мақаласының тақырыбы – асфальт қоспаларына өнеркәсіптік болат өндірісінің жанама өнімі болып табылатын қожды қосу арқылы алынған шлак асфальты. Мақалада шлак жол асфальтын пайдалану бойынша соңғы ғылыми жұмыстарға шолу берілген. Бұл мақалада қож асфальтбетонының құрамы, технологиялық және физикалық-механикалық сипаттамалары қарастырылады. Шлактың материалдың беріктігіне, сынуға төзімділігіне және деформациясына әсерін зерттеуге ерекше назар аударылады. Авторлар оның өнімділігі мен жабынның беріктігін жақсарту үшін қож асфальтты түрлендірудің әртүрлі әдістеріне шолу жасайды. Сондай-ақ мақалада қож асфальтбетонының экологиялық маңызы ерекше атап өтілген. Осы мақалалардың жалпы талдауы жол құрылысында тиімді және экологиялық тұрақты материал ретінде қож жол асфальтбетонын пайдалану мүмкіндігін көрсетеді. Дегенмен, оның әртүрлі климаттық және жол жағдайларында қолданылуын растау үшін қосымша зерттеулер мен тәжірибелік сынақтар қажет. Мақаланың қорытынды бөлімінде тұрақты жол құрылысы контекстінде қож асфальтбетонының маңыздылығы қарастырылады. Қож асфальттың жол инфрақұрылымын салу және күтіп ұстау шығындарын үнемдеу, сондай-ақ оның беріктігі мен тұрақтылығын арттыру мүмкіндігіне баса назар аударылады. Қорытындылай келе, мақалада қож асфальтбетонға жалпы шолу, оның артықшылықтары мен жол құрылысында пайдалану перспективалары берілген.

Түйін сөздер: асфальтбетон, болат шлактары, кремний газы, жол төсемдері

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