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SELECTION OF EFFECTIVE MATERIAL FOR ROAD CONSTRUCTION

The object of research is the technology of road surface construction using alternative materials and the possibility of introducing automated systems to increase productivity. The main hypothesis of the study lies in the found alternative material, with the help of which it is possible to reduce the cost of road construction and increase the quality and service life. To reduce the cost of roads, it is necessary to create new construction technologies using innovative or alternative materials, use the latest mechanisms and introduce automated and robotic systems. This can be achieved if to carefully study the technology of the construction process device. One of the materials of the road surface is crushed stone, gravel and sand. Let's consider as one of the alternative options for mining waste – crushed slag. When determining the main physical and mechanical properties of crushed slag, the standard method for testing crushed stone in stationary laboratory conditions was used. In the course of the study, the methods of system analysis and generalization were used, as well as the method of material testing. The authors of the work analyzed the technological processes of road construction and proposed a material based on the test results – crushed slag from a ferroalloy plant. During the tests, it was confirmed that the material is an alternative quarry crushed stone. Ferroalloy crushed stone has the same field of application, strength, density, frost resistance, but the cost is an order of magnitude less than a ton, creates an economic effect of 31.93 USD per ton. This makes it possible to reduce the cost of the road surface and ensures the quality that meets the regulatory requirements, and the production of modern technologies will reduce the time standard at some construction sites.

When testing crushed slag, the results obtained confirm that this material meets all the requirements and may well replace granite crushed stone in the construction of roads for various purposes. Such material can be used not only in Ukraine, but also in countries with similar requirements for the composition of the roadway.

Keywords: history of road construction, road surface, quality of highways, modern technologies, crushed slag.

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1. Introduction

In modern conditions, the road is an integral part of human life. Countries, regions, settlements and their areas are interconnected by various transport routes. The paths enable humanity to maintain personal and business connections between settlements. In order to understand how long the journey will take, it is necessary to roughly calculate the speed of movement and the time taken to reach the destination. The life of the person often depends on the condition of the roads [1].

So, the authors of works [2, 3] investigated the condition and structural structure of the road surface. In [4–6], the technological processes that were used in different periods of road construction are studied. On the basis of experimental research and calculation, substantiations of the effectiveness of an alternative solution in comparison with existing technologies were given.

In this direction, an urgent further development is the attraction of innovative or alternative materials, with the help of which the cost will decrease and the quality and service life of roads will increase.

This work describes the problems of modern road construction and their operation in the example of Ukrainian roads. Ukrainian roads are recognized as one of the worst in the world. According to the data of the 2019 research,

which is carried out by American sociologists of the Gallup Institute, in the rating of road conditions Ukraine took 114th place out of 137. Most of the roads in Ukraine are in a terrible state. The State Road Service admits that in Belarus funding per kilometer is three times more than in Ukraine. 2020 under the program «Big construction» should be repaired, and built 6.5 thousand km (in fact, 5.1 thousand km of roads, which are in perfect condition). And it will take (with funding) only 4.5 years to repair all Ukrainian roads as fast as it is now [7]. In different areas, terrible roads are usually repaired with patches or individual pieces. At the same time, the quality is low and their service life is minimal (season or year). Therefore, it is relevant to select a material that will reduce costs, but at the same time improve the quality of the road surface.

Thus, *the object of research* is the technology of paving construction using alternative materials and the possibility of introducing automated systems to increase productivity. *The aim of research* is to select a technology that can reduce the cost and increase the service life of roads.

2. Methods of research

To solve this goal, it is necessary to study the history of road construction, technologies in road construction and select an alternative material to the existing ones.

To reduce the cost of roads, it is necessary to create new construction technologies with the involvement of innovative or alternative materials. Studying the history of road construction, developing a classification, as well as searching for new solutions, studying the physical and mechanical characteristics of alternative and new materials gives a chance to improve the quality of roads with savings on the implementation of these technologies [1].

The study of information sources allowed the authors to determine the results of works close to the research topic [3, 8, 9]. The analysis of these works made it possible to define the concept of the road, the history of road construction, and the technological regulations of the work.

The concept of «road» is a path of direction, designed to move technical equipment and people. The road, based on the type of transport, moves along it, can be road, rail or air. Let's take a closer look at highways. A road is a part of the transport infrastructure intended for the movement of motor vehicles and includes associated structural elements (road surfaces and roadways) and artificial engineering structures, as well as land plots on which it is located.

Studying the history of the creation of roads, the most ancient roads date back to the 4th millennium BC. At the beginning of this millennium are: the road found near the city of Ur in Mesopotamia, and the road found near the English city of Glastonbury. One of the most ancient roads in Europe, called Mir-Trek, was discovered on the island of Great Britain. The road, built in the XXXIX century BC, consists of superimposed crossbeams of young ash, oak and linden and oak flooring on top of them. The oldest paved roads are those found on the island of Crete. Cretan roads are covered with limestone slabs up to 15 cm thick, dating back to the 3rd millennium BC e. Brick for paving roads was first used in ancient India around 3000 BC. Roads with a stone surface existed in the Hittite kingdom, Assyria, the Achaemenid empire. During the reign of the founder of the Chinese Qin dynasty – Qin Shihuang (221–210 BC) – a network of roads with a total length of 7.5 thousand km encircled the country; the roads were 15 m wide with three lanes, with the central lane intended for the emperor. On the main roads of Rome, hotels were built for individuals, and for officials – stations at which horses were changed, it was possible to get accommodation and food, residents of a nearby village held the station (Fig. 1). The total length of Roman roads (including dirt and gravel) by the 4th century BC That is, it amounted to 300 thousand km [1, 5, 6].

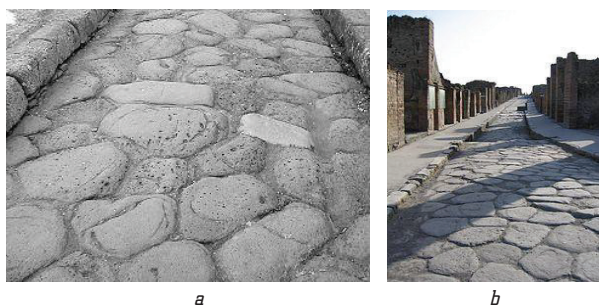


Fig. 1. Photo fragment of the Roman road in Pompeii:

a – photo fragment of cobblestone pavements; *b* – general view of the road

Road work in the Middle Ages of Kyivan Rus mainly consisted in the repair of dirt roads and the construction

of bridges. During its existence (XII–XVI centuries), the monastic order of Brothers-Bridge Builders has built about 1700 bridges [1, 4].

The technology of the roads of the past was as follows:

- conducted research of the territory;
- geodetic works were carried out;
- preparation of the territory was carried out, namely, trees, shrubs, sprouts were cut down, which interfered with the construction of the road;
- small depression was dug;
- further was the basis of the road.

For the base, stone blocks were taken, which served as the foundation of the road. There were gaps between the stone blocks that served as drainage. The next layer was applied from sand or gravel to level the surface. The top layer was applied from fine sand, gravel, lime or earth. This road had a curved surface. This system allowed rainwater to drain into drainage ditches dug along the road [1].

The modern structure of the roadway differs from the past and consists of the following layers: soil base, base, additional base layer, coating layers. Fig. 2 shows the structure of the main layers of the coating. The thickness of the structural layer in all cases must be at least 1.5 times the size of the largest fraction of the material used in the layer.

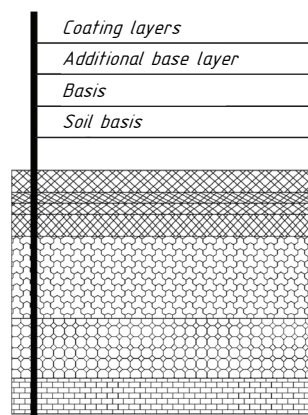


Fig. 2. The main layers of the road surface

The choice of pavement depends on: general requirements for the road as a transport structure, pavement design and type of pavement, the number of layers that provide strength, load, frost resistance and other characteristics of materials.

One of the materials of the road surface is crushed stone, gravel and sand. In this case, let's use an alternative solution to mine waste, especially in large industrial cities, where a lot of such waste has been accumulated – this is crushed slag. For this purpose, surveys of crushed slag were carried out.

3. Research results and discussion

When determining the main physical and mechanical properties of crushed slag, the standard method for testing crushed stone in stationary laboratory conditions was used [10].

The results obtained for crushed stone of ferroalloy production turned out to be the same as for open pit crushed stone. Namely: the grain size corresponds to a fraction of 5–10 mm; grade for crushing M1400, grade for abra-

sion I-2, grade for frost resistance F300, radioactivity (no more than 370 Bq/kg), i. e. the 1st class.

A number of laboratory tests were carried out to confirm that crushed slag can be easily used in road construction. In this regard, two versions of the samples were made: option 1 – typical, consisting of sand (S), cement (C) and quarry crushed stone (CS); option 2 – consisted of sand (S), cement (C) and slag crushed stone (CS).

In the experiments, let's use a dry mixture of the composition C:S:CS (1:2.5:1.5). Option 1 – used quarry crushed stone with a fraction of 5–10 mm, cement grade 400, option 2 – used crushed slag with a fraction of 5–10 mm, cement grade 400, the nozzle diameter was chosen 35 mm, hose length – 30 m, air consumption 8 m³/min.

The quality of the road surface is affected by the distance from the nozzle to the repaired horizontal surface. This parameter varied from 0.9 to 1.5 m at fixed values of W/C=0.4 (water-cement ratio) and the speed of the mixture exit from the nozzle of 130 m/s.

To determine the amount of rebound, a 3×4 m section was taken, fenced with 1 m high shields. The section was covered with construction film, on which the equipment was installed. Before feeding, the concrete mixture was weighed and fed into a mold. Then, the mixture that turned out to be in shape was collected, dried and resolved. The data obtained were entered in Table 1.

When comparing the options (Table 1), the strength indices of the sprayed concrete are almost identical. As can be seen from the data in Table 1, the optimal distance from the nozzle to the concrete surface for both the first option and the second is 1.1 to 1.3 m. The compressive strength and bending strength may differ at different distances compared to the obtained strength characteristics at the optimal distance of 22–30 % and 32–39 %, respectively. The minimum amount of rebound is obtained at an optimum distance of 1.1 to 1.3. This is due to the fact that with an increase in the distance from the nozzle to the surface, the mixture is not extinguished, and at a small distance, it loosens.

Another equally important indicator of the road surface is abrasion. This is due to the influence of the intensity of road transport wheels on the road surface.

Previously, sample cubes 70×70×70 mm were cut from a finished reinforced concrete slab. Then these samples

were placed in a special chamber with steel bullets. The essence of the method is to determine the weight loss of the test sample. This specimen is subject to the abrasion of the steel balls. The steel ball is analogous to the tires of machines that affect asphalt concrete [10].

The abrasion of the sprayed concrete C_{ab} , cm², is calculated by the formula:

$$C_{ab} = \frac{m_1 - m_2}{F_{mb}},$$

where m_1 – the mass of the sample before testing, g; m_2 – the mass of the sample after testing, g; F_{mb} – the erasure area of the sample edge, cm², accurate to the first decimal place, which is determined according to PNST 106-2016 (preliminary national standard).

The results obtained are entered in Table 2.

As can be seen from the results obtained in Table 2, the abrasion according to the second option is much less. So, crushed stone of ferroalloy production can be used for road surfaces.

And another equally important indicator is cost. Table 3 shows the comparative characteristics of various materials.

As can be seen from the obtained indicators in Table 3, crushed stone of ferroalloy production has the same field of application, strength, density, frost resistance, but the cost of crushed stone slag is 2.48 USD per ton. That is, the economic effect is from the cost 31.93 USD. This makes it possible to reduce the cost of the road surface.

Most of the traditional roadwork equipment can be automated to speed up construction times. They can be upgraded to offer truly stand-alone modes of operation, or they can simply work in conjunction with human counterparts as a more general mechanism.

Automation and robotization of mechanisms in the technology of road construction on flat surfaces is a matter of software and quality control of the work performed. On the performance of work on difficult terrain and inclined surfaces, it is necessary to use other specialized equipment. For this type of work, portal work can be used [11], which will perform work of various types: soil movement, crushed stone foundation, concreting work, etc.

Table 1

Strength of sprayed concrete the amount of rebound depending on the distance of the nozzle to the concrete surface according to options

Indicators	Distance to the concrete surface, m															
	0.8		0.9		1		1.1		1.2		1.3		1.4		1.5	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
R_c , MPa	20.8	21.7	23.5	24.3	24.9	24.9	25.9	26.5	27.8	27.9	25.6	26.4	23	23.4	19.4	19.8
R_b , MPa	5.3	5.4	5.9	6.1	6.2	6.7	7.4	7.8	7.6	7.9	6.4	6.6	5.3	5.5	4.5	4.8
Rebound amount, %	26.6	26.5	21.2	21	17.4	17.3	14.2	14.1	12.1	12	14	13.9	16.9	16.9	22.1	22.1

Note: R_c – compressive strength; R_b – bending strength


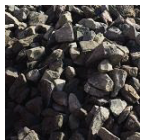


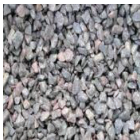
Table 2

Abrasion by comparative options

Options	Abrasion area of the sample	Sample weight before testing	Sample weight after testing	Weight loss, %	Abrasion	Average value
1	51.3	652.4	630	3.5	0.44	0.49 (0.5)
	50.5	673.3	634.8	5.8	0.76	
	50	644	629.5	2.3	0.29	
2	49.7	712.7	692.3	2.86	0.41	0.37 (0.4)
	50.5	731.3	716.8	2	0.29	
	50	724.2	703.8	2.8	0.41	

Table 3

Comparative characteristics of various materials

No.	Indicators	Options				
		1	2	3	4	5
1	Name	Stone for gabions (rubble stone) Crushed granite, fraction 70–150	Stone for gabions (rubble stone) Crushed granite, fraction 100–250	Crushed granite, fraction 40–70	Crushed granite, fraction 20–40	Ferroalloy crushed stone, fraction 5–10
2	Application area	Gabion filler road Construction Landscaping Foundations	Gabion filler Road construction Landscaping Foundations	Road construction Railroad construction	Foundations Road surface High-strength concrete	Road construction Landscaping Foundations
3	Strength	M1200	M1200	M1200	M1200	M1400
4	Frost resistance	F300	F300	F300	F300	F300
5	Density, t/m ³	1.50	1.46	1.36	1.36	1.50
6	Labor intensity, man-days	20.58	20.58	20.58	20.58	–
7	Production per shift, m ²	143	143	143	143	–
8	Duration per 100 m ² , h	10.8	10.8	10.8	10.8	–
9	Cost per ton, USD	34.41	34.41	34.41	34.41	2.48
10	Description					
11	Economic effect from material cost	–	–	–	–	31.93

The use of alternative materials with the classic technology of road construction in combination with automated and robotic mechanisms allows not only introducing savings, but also increasing work productivity. Thus, innovations are able to restore and create a new transport infrastructure in Ukraine an order of magnitude faster than it is happening now.

4. Conclusions

Based on the studied material from information sources, a modern classification of roads by value, category, technical standard and type of coverage was developed, which meets the standards of different countries.

When studying the structure of modern roads, it was revealed that one of the components is quarry crushed stone. One of the alternative options was offered crushed slag, which is a waste of metallurgical production.

When testing crushed slag, the results obtained confirm that this material meets all the requirements and may well replace granite crushed stone in the construction of roads for various purposes. Such material can be used not only in Ukraine, but also in countries with similar requirements for the composition of the roadway.

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