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FEATURES OF THE PAVEMENTS CONSTRUCTION, CONSTRUCTED WITH THE USE OF SLAG MINERAL MIXTURES

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Abstract. In the practice of building of capital types of pavements eventually established the principle of one-time capital investment, according to which the physical and mechanical properties of structural layers to be formed largely under construction and start of operation of the road to take the calculated value. According to this principle calculated characteristics of soil reinforced with inorganic binders, defined in the standard period of solidification, which is taken for 28 days just as is customary during testing of cement products. It is assumed that after 28 days of hardening of soil samples fortified gaining at least 70% of maximum strength. Consistent implementation of this principle encourages use for strengthening of soil-early type of inorganic binders cement and virtually eliminates the possibility of a wide use for these purposes is slowly hardening of mineral binders which, for example, steel slags.

Keywords: pavements construction, steel slags, binders, road, surfaces of soil.

Introduction

Along with the above technologies coexist in the road opposite principle phasic principle of building local road network nonrigid perish under which technical and quality eksnluatatsiyni pavements gradually improving as the increase in traffic. Consistent implementation of this principle implies widespread use in road construction waste and by-products industry. Including the reinforcement of soils and intensifying implementation of semi-rigid structural layers of road pavements, constructed using slow hardening of mineral binders. They are distinguished by a gradual increase in the strength characteristics during operation in proportion to traffic growth.

To strengthen the soil is recommended to use lime, ash removal TPP, lime-ash and slag lime-slow hardening binder. For regulatory testing time period taken 90 days. The introduction of a new regulatory test duration fortified soil approve a functional nature of this indicator, and therefore offers a real prospect for use not only the above-mentioned species of native binding but other potentially active waste and by-products, such as the steel industry.

Statement of a problem

Considering the long-term positive experience of building bases and surfaces of soil, fortified by steel slag, in the past twenty years, the technique of designing DerzhdorNDI part shlakohruntovyh mixtures. The basis of this technique is the classification hydraulically active binders and secondary products of the metallurgical industry in terms of estimated lifetime hardening.

Experimental test results of samples of cement, slag soil mixtures at different times of hardening indicate that the expected lifetime of hardening (tp) essentially depends on the type of mineral binder varies in a wide range of 28 to 1080 days. To rapidly hardening binders and the first group of slow hardening binders (tp) quantitatively consistent with the standard period of testing.

Table 1.

Indexes	Types binders			
	Quickly-hardening	Slow hardening Groups		
		I	II	III
Estimated hardening time, no more days	28	90	360	720
Name of binder	Portland-cement and its variety, cement dust	Ground Granulated slag (MGS), slag lime binder (SLB), electro fusion (EF)	Dump blast furnace slag (DBS) crushed granulated slag (CGS)	Granulated slag (GSH) Ferrochromium slag (FS)

As expected lifetime is not matched with the rhythm of the technological cycle of construction coatings and substrates, it really can not be used in laboratory practice in the selection of the optimal composition of the mixture

as a normative term tests. It is therefore recommended for all types of mineral binders introduce a single regulatory testing period which is 28 days. In this case, the soil-early fortified mineral binders, tH = tp

To bring the indicators of physical and mechanical properties of soils, mineral fortified slow hardening binder recommend that activation of soil mixtures slag Portland cement M-400, the required number of which Du% to the mass of dry soil mix slag determined by the formula:

$$D_u = 3n, \quad (1)$$

where: n – group number slowly hardening binder on the proposed classification. Multiple experimental verification of this dependence has shown satisfactory convergence.

In addition, the technique of DerzhdorNDI analytical determination of the design characteristics of slag soil. Limit compressive strength of slag soil samples at the estimated time hardening under that procedure determined by the formula:

$$R_{shg} = R_{shg} \cdot D^{\alpha}_{sh}, \quad (2)$$

where: R_{shg} – limit slag expected lifetime hardening, MPa; D_{sh} – amount of slag in the slag mineral mixture; α – conventional qualitative characteristics of the mixture is determined experimentally.

$$R_{sh} = R_{max} \cdot H^{e}, \quad (3)$$

where: R_{max} – branded belit strength cement GOST 10178-76, is 30 MPa; e – base of natural logarithms; H – the degree of saturation ortho silicate slag calcium.

Experimentally determined that the limit compressive strength of slag at the estimated time hardening can be determined by the relationship:

Number passive SiO_2, that is not bound ortho silicate calcium, determined by the formula:

$$SiO_2 = 0{,}59\ Al_20_3 + 0{,}67\ МпО. \quad (4)$$

Results generalization of experimental data showed that between the calculated using the formula (1) and the experimental data values R_{sh} there is a close correlation with a correlation coefficient of 0.93

In assessing the quality of soil fortified slag other than ultimate strength in compression important indicators are normalized strength in tension bending (τss) and frost K_{ss} factor in the expected lifetime hardening.

Specified performance is highly correlated with the convergence R_{ss}:

$$\tau shg = 0{,}86\ R_{shg}, \quad (5)$$

$$K_{shg} = 0{,}6(1+0{,}1R_{shg}). \quad (6)$$

The estimated consumption of cement, depending on the required strength class slag soil, type of soil and slag activity is determined by the formula (1).

Estimated slag soil modulus E_{ss} calculated as follows:

$$E_{shg} = 125\ R_{shg}, \quad (7)$$

The recommended method of determining the quality of road – building materials semi-rigid type offers endless opportunities for involvement in the sphere of material production of many types and amounts of potentially active slow hardening of industrial waste, significantly extends the use of reinforced soil in road construction and makes it possible to increase the technical and economic characteristics of road construction because it combines the specificity of the transport roads and features of formation pavement structure.

Accumulated by that time domestic and foreign experience of experimental and industrial construction, and operation of roads constructed to draw conclusions about the advantages and merits semi slag mineral bases pavements.

So, slowly hardening granulated blast furnace slag as binders for mineral fortification of various materials and semi-rigid type arrangement of bases have a number of positive qualities and advantages.

Self-preservation of quality hydraulic activity

During granulation blast-furnace slag on separate granules produced acidic membranes which protects the granules from the effects of weather conditions and gives it relative stability. The presence of the protective membranes can explain the stability of the slag heaps of granules in which almost no solidification phenomenon, and it is in contradiction with the theory of slag cement production, where hydraulic granulated capability is only possible after the mechanical grinding.

High adaptability

Granulated slag does not require special storage space and can be stored long term in piles outdoors.

Granulated slag as binder can provide advance and stored at sites around objects.

For transportation Grand slag does not require special vehicles can be transported to construction sites in open wagons or dump.

For mixing granulated slag mineral materials can be used mixing different soils. Granulated slag practically does not emit dust and sanitary-hygienic regarding its use does not require the implementation of special measures.

Slag mineral mixes are less sensitive to changes moisturizing treatment compared to cement and lime mineral mixtures technologically important.

Slag mineral mixes are less sensitive to changes in temperature, moreover, pre-freezing mixtures such a positive impact on the structure of the material. After freezing hardening processes occur more intensively. Therefore, in the arid steppes of southern Ukraine construction slag mineral bases in the winter is not only possible, but advisable.

The use of granulated slag to strengthen mineral soil materials and can extend the construction season.

Slow formation of slag mineral mixtures structure enables workflow stretch of time without compromising quality.

The technological gap between the mixing slag mineral mixture and the final arrangement of structural layer can be extended to 15 days.

After completion of the consolidation and compaction of mineral slag road can be operated without arranging ways.

Slag mineral mix well finished compaction during operation, especially in the early days, and this has a positive effect on the structure of the material and increase its strength. Increased strength slag mineral materials in this case occurs by increasing density, and by disclosing new surfaces slag granules and getting through this additional portions cementing substance. The share of the second factor is much higher than the first, especially when using large debris soil.

Slow formation of slag mineral mixtures structure provides the possibility of hardening a direct result of vehicle load and can not unite in a single technological process of preparing mixtures of streamlining and consolidation and not create special conditions for storage and transport of slowly hardening binders (if mixing arrange basis granulated slag and mineral material on roadway) or slag mineral mixtures (if prepared in the mixer).

The relative strength difference slag mineral materials depending on the accuracy binder costs are several times lower than in the case of cement, which also determines the processability high slag mineral bases.

Slag minerals mixes through their high technology widely used as a leveling layer of reconstruction and major repairs of roads, as have the advantage over other materials, such as crushed stone, gravel and bitumen minerals mixes. Crushed stone and gravel in the dispensation of the old pavement are artificial substances accumulating water, which accumulates very negative impact on the strength and stability as the old pavement and road construction in general. The use of bitumen mineral mixtures, especially in the peak of acute energy crisis is not always economically feasible, particularly in cases where the thickness of the strengthening of pavement is over 20 cm. Therefore, the reconstruction, strengthening and repairing roads most appropriate to use dense materials with minimal open porosity, what are the slag minerals mixture.

Slow hardening slag minerals mixes allow the equalization of old coating and pavement reinforcement layers without closing the road to traffic (while not compromising the quality of the material), and therefore no additional cost for the construction of additional roads.

The ability to strengthen over time in proportion to the increasing demands of pavement due to increased traffic

The strength of slag mineral bases grows for 1-5 years. The analysis of the nature of hardening slag mineral bases made it possible to distinguish the game in this period: start setting time to 28 days; hardening of 28 to 360 days; slow hardening more than 360 days. Established that ¾ strength values slag minerals mixes acquired in the period from 28 to 360 days.

Increase of strength occurs by increasing the density of the vehicle under the influence of stress and resulting slag grinding beads that ensure the growth of hydraulic activity.

Seals slag mineral mixtures during the construction and operational results in the formation of structural layer that takes traffic load in the compression stage. This allows the maximum use of bearing and distribution properties shlakomineralnyh bases, which is an important advantage of semi-rigid pavements bases.

Abrasiveness and skeletal

Granulated slag as the binder is a granular bulk material with high roughness individual granules and therefore has good abrasive properties. Additive slag to clay soil significantly reduces energy process of loosening the soil and improves the quality of the mixture. Increased roughness of granules of slag mixing processes dominate over the processes of separation and therefore slag minerals mixes with high quality.

As grained (granular) slag material has the property taken compressive and shear stress, so it is somewhat skeletal material.

Due to the slow curing granulated slag long time retain their potential hydraulic properties that actively occur during operation when under the influence of vehicle load is deforming structures slag mineral material and the formation of new hydraulically active surface granules which interact with water to form a solution hid cementing and hardens like glue, cracks and other deformations.

Experimental research

Chemical compound of steel slag is presented in Table 2 and Fig. 1.

Table 2. Chemical compound of steel slag

Material	Chemical compound [%]							Lime factor, M_o
	SiO_2	Al_2O_3	CaO	MgO	MnO	FeO	S	
Steel slag, dense fine-grained material of grey colour	28.3	12.0	31.0	9.0	5.6	13.4	0.7	1.1

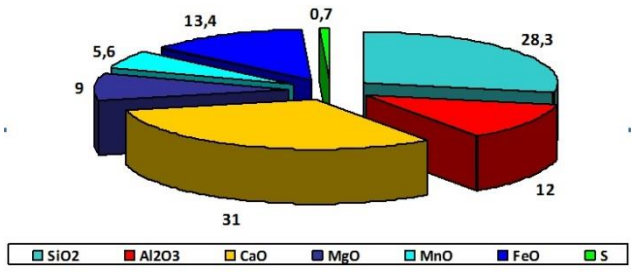

Fig. 1 Chemical compound of steel slag

On the basis of chemical compound data, lime factor (M_o), activity module (M_a) and quality factor (K), characterising the hydraulic activity of slag, are estimated:

$$M_o = \frac{CaO + MgO}{SiO_2 + Al_2O_3} = \frac{31.0 + 9.0}{28.3 + 12.0} = 0.99;$$

$$M_a = \frac{Al_2O_3}{SiO_2} = \frac{12.0}{28.3} = 0.42;$$

$$K = \frac{CaO + Al_2O_3 + MgO}{SiO_2} = \frac{31.0 + 12.0 + 9.0}{28.3} = 1.84.$$

Depending on the quality factor and content of compounds, all kinds of slag are divided into three grades, according to the Ukrainian Standard GOST 3476-74 (Table 3 and Fig. 2).

Table 3. Slag grades

Indicators	Grade		
	1	2	3
Quality factor *K* (Fig. 3), not less than	1.65	1.45	1.20
Content of Al_2O_3 [%], not less than	8.00	7.00	not normalised
Content of MgO [%], not more than	15.00	15.00	15.00
Content of TiO_2 [%], not more than	4.00	4.00	4.00
Content of MnO [%], not more than	2.00	4.00	4.00

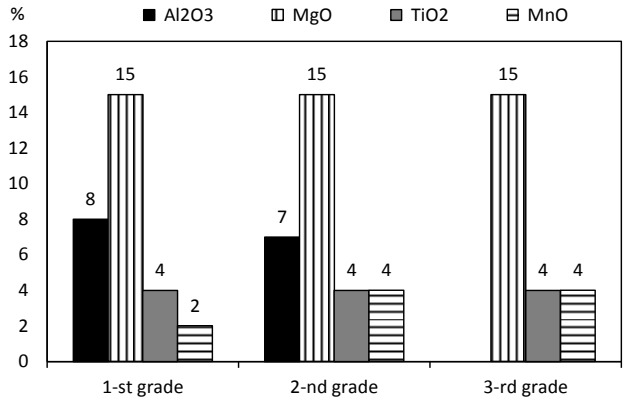

Fig. 2. Slag analysis depending on compounds inclusion, according to the Ukrainian Standard GOST 3476-74

Physical and mechanical properties of crushed material produced from steel slag are presented in Table 4. For comparison, parallel trials of granite crushed material, taken from the *Klesivsky Quarry* (Ukraine) were executed.

Having analysed the data presented in Table 3, we may come to a conclusion, that physical and mechanical properties (strength, crushability and water absorption) of crushed material produced from recrement slag are higher, than the ones of granite, and they meet the requirements of the Ukrainian Standard DSTU B V.2.7-74-98, which means that this material can be used for arrangement of pavement layers and for road-base manufacturing.

It is known that binding properties of slag produced by metallurgical plants are characterised and defined using the following indicators:

– hydraulicity – strength at compression of samples produced by tamping the mix of crushed slag and water;
– resistance to disintegration of slag mix samples in water;
– swelling of slag (mineral) powder;
– hardening time.

Table 4. Physical and mechanical characteristics of crushed material produced from steel slag

Indicators	Crushed material produced from steel slag	Granite crushed material (*Klesivsky Quarry*)
Real density [g/cm^3]	3.45	4.20
Average density [g/cm^3]	3.84	4.35
Bulk density [kg/m^3]	1800.00	1850.00
Porosity [%]	5.40	7.50
Water absorption [%]	2.10	3.40
Grade according to frost resistance	High, F 150	High, F 150
Grade according to crushability	M 1200	M 1000
Hardness in 10-point scale [points]	6÷7	–
Grade according to abradability	High, ST-1	High, ST-1
Strength at compression in the cylinder [MPa]	7.40	5.40
Content of lamellar (hearth bottom) and needle-shaped grain	Cube-shaped group, 12	Cube-shaped group, 15
Clay content in clots	–	–

Definition of these indicators was carried out and the research results are presented in Table 5.

Table 5. Binding properties of electric steel-smelting slag

Indicators	Test results
Strength at compression [MPa]	8.5
Resistance to disintegration [%]	
Silicate steel-smelting slag	0.9
Ferrous steel-smelting slag	1.8
Swelling [%], not less than	58
Hardening time (the beginning of hardening), in minutes	14

Having analysed the data presented in Table 4, we may come to a conclusion, that electric steel-smelting slag has sufficient binding properties, which will prolong working life and enhance strength of constructive layers of road pavements when applied.

Due to the fact that crushed material and mineral powder produced from slag will be used for preparation of asphalt concrete mixtures, the research of organic binder (bitumen) adhesion properties was carried out.

Widespread use local mineral materials.

Slow hardening granulated blast furnace slag is both astringent and skeletal material and may be due to specific properties of this very effectively used to strengthen a wide range of local materials that are suitable for strengthening other binders.

The problem of building foundations semi pavements is one of the important and promising in the road of sci-

ence and practice. These bases allow to form a durable and high-strength construction, which for technical performance and economic and technological characteristics higher than typical solutions, especially during the acute energy crisis.

Use mineral materials and soil, fortified slag binders (lime-slag binder, dumping domain, hammer, crushed and conventional granular, ferro chrome and steelmaking slag with the addition of cement, cement kiln dust or lime) as structural layers of pavements appropriate throughout Ukraine in the first and second types of terrain for moisture on roads grid II in technical categories.

Slag minerals materials as structural layers of semi-rigid type recommended for the device:

- transitional surfaces with a protective layer on local road network;
- Lightweight bases under cover of gravel and crushed stone material processed liquid organic binder, and under cover of asphalt cold and wet organic-mineral mixtures;
- upper and lower layers of foundations under cover with hot bitumen and tar mineral mixtures;
- upper and lower layers of foundations in the construction of capital types of coverings on public roads network all categories.

Surface type and pavement construction is selected based on the transport and operational requirements, projected road category, given the composition and intensity of expected traffic and weather conditions on the basis of technical and economic comparison of options, providing maximum reduce energy materials, technologies and design solutions. This simultaneous to reduce capital investments and increase their economic efficiency enhancement expected phasic pavement.

Purpose and calculate the thickness of structural layers of pavements are being built with the use of slag mineral mixtures, performed according to the requirements of "Instructions for the design of road pavements non-rigid type" (VSN 46-83). In this case top layer of subgrade, compacted to a depth of 20-30 cm density corresponding to not less compaction ratio of 1.0, considered as constructive layer, the strength of which into account when calculating the pavement. Therefore the design bases or slag mineral surfaces calculated modulus of subgrade according to III and IV road-climatic zones increase by 30 and 40% compared to values for modulus VSN 46-83.

This rule is defined as a synthesis of many years of operating experience with pavements reinforced soil. Repeated experiments HARU, DerzhdorNDI, SoyuzdorNDI observed that the strength of the roadbed beneath layers of impermeable material that is slag minerals mixture, 30% in III and 40% in the IV Road climates higher than in porous layers of gravel, sand or gravel.

Bases of slag mineral mixtures ordering one or two layers. In this case calculate the thickness of each layer should be at least 10 cm and not more than 22 cm thick body. In the two-layer arrangement bases slag minerals mixes for the bottom layer is prepared by mixing method canvas ways, and to top - a stationary or mobile mixing machines.

Slag mineral bases to ensure optimal conditions for the formation of their structures necessary to put layers of dense mineral mixtures processed organic or inorganic binders. Allowed crushed stone arrangement of layers thicker than 14 cm deep impregnation with an organic binder.

Surface of slag mineral mixtures are transitional and built with a protective layer on local roads with traffic to 3,000 cars per day. After 2-3 years of operation of these coatings should be strengthened by arrangement improved types of coatings.

Necessary information about selection of the slag mineral mixtures and their test given in "Benefits for the construction of coatings and bases of highways and airfields from soils reinforced with astringent materials, to SNiP 3.06.03-85 and SNIP 3.06.06-88".

Conclusions

1. The research showed that the steel slag can be used as crushed rock aggregate and mineral powder in road structures for preparation of asphalt mixture. Sufficiently high hydraulic activity allows recommending its use as an inorganic binder with addition of portland cement and lime.
2. Crushed slag, compared with crushed granite, ensures better performance indicators pertaining to road structure layers. For this reason, increase in service life (especially during the first five years) is observed. Thus, due to the use of electric furnace steel slag, durability of road structures can be increased, their cost – significantly reduced, and the construction season – extended.

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