THE BULGARIAN EXPERIANCE IN USING SLAG IN ROAD CONSTRUCTION

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ABSTRACT

The paper examines the Bulgarian experience accumulated in using slag in road construction. It is emphasized on the different types of slag in the separate construction layers in the road structure: to strengthen the foundation bed, in the road base and bitumen coating.

Keywords: Types of slag; road structure; road bases

1. INTRODUCTION

The paper is dedicated to the use of metallurgy slag in Bulgaria and their application in road constriction.

Slag is obtained with the production of steel in different ways – open-hearth, converter and steel electric furnace production.

We will examine the slag from ferrous metallurgy: (blast-furnace, open-hearth, converter, ferrous alloy) and from non-ferrous metallurgy (copper, lead and zinc production) for bases and asphalt layers in road construction. The slag storage on slag dumps near the main production creates a number of environmental problems and the respective financial costs. The slag from ferrous metallurgy are of the greatest amount, up 1,300 thousand t. They have been applied in practice with road construction where the annual necessity of mineral materials is up to 2,000 thousand t.

In historical aspect the use of slag in road construction began in 1862 in some countries such as Russia, France, Germany, etc.

The application of slag in Bulgaria began in 1970s and it was used in bulding A 2 "Hemus" motorway, III-801 road "Vakarel – Belitsa", III-103 road "Elin Pelin – the station of Elin Pelin" as well as for building municipal 649 SOF 1110 road in the section from "Golyamo Buchino - Malo Buchino" and the street connections to it, as well as for building the ring-road of Sofia.

2. BASE STANDARDS

There are two standards of using slag that are in force: Bulgarian State Standard BSS 9341-78 "Blast and steel-production slag for construction purpose" and BSS 14610-78 "Metallurgical slag for road pavements".

The Bulgarian State Standard BSS 9341-78 is more general and, according to it, slag is classified by three criteria:

- According to the way of production – blast, steel production, converter, open-hearth, electric steel production
- According to the way of cooling – granulated and non-granulated;
- According to the way of taking the slag – without any additional processing and by additional crushing.

This standard defines the technical requirements for taking and accepting samples and methods of testing the slag that is used in construction as a complementary material for road embankments, filling and ballast prisms for temporary railway lines.

The Bulgarian State Standard BSS 9341-78 refers to the metallurgic slag – granulated and non-granulated – obtained with the production of cast iron and steel; it is used to build road and street pavements.

In conformity with the technical requirements, the non-granulated slag is divided into three classes, as class 1 is of best indices.

According to the Bulgarian legislation, the standards mentioned above are not obligatory for the producers and have only a recommendable character.

The application of similar standards from other countries to the slag produced in Bulgaria is not a good approach because the slag chemical composition determining its technical qualities is different even at factories on the territory of one and the same country.

3. SLAG USING IN ROAD STRUCTURE

3.1. Blast-furnace slag

The blast-furnace slag is of greatest amount, 900,000. t per year in the country, and it is the most significant for road constriction. It is produced on industrial sites at "Stomana Industry" in the town of Pernik and "Kremikovtsi" AD, Sofia. For a certain period of time a crushing and sifting installation for metal separation of the slag existed on the slag dump at "Kremikovtsi" AD, Sofia.

The blast-furnace slag from the slag dumps is a good material for road construction. In some cases, the obtained secondary minerals (calcite and ferrous hydroxides) в in the slag after its long stay on the slag dump are the reason for its hardening and to be taken, it is necessary to be detonated.

The grain metric composition of the processed slag is as follows:

- an ordinary fraction of 0–120 mm or 0–80 mm for making road bases in road construction;
- a fine-grained fraction of 40–100 mm;
- fractioned slag of 5–20 mm or 20–40 mm for complementary material in asphalt layers;
- a sifted (slag sand) fraction of 0–5 mm as a fine-grained complementary material in asphalt layers.

The slag that has passed from the slag dump through the crushing installation is sent to the consumer for the needs of road construction or to the crushing and separating installations for producing two fractions of gravel, of 5–40 mm and 40–75 mm and slag sand of a 0–5 mm fraction.

The mechanical strength of the slag from the slag dump is quite heterogeneous. The compressive strength varies from 20 to180 MPa.

In Bulgaria a number of studies have been carried out how to use the open-hearth slag from "Kremikovtsi" AD for building road bases . A several variants of road bases have been accomplished. The following four variants were applied in the road section I-6 "Sofia – Pirdop":

- type 1 a base of a sized crushed slag fraction of 20–75 mm and a wedging fraction of 5–20 mm with a thickness of 40 cm. A two-layer pavement of asphalt concrete thick 4 cm was laid on the base;
- type 2 a base of a sized crushed slag fraction of 20–75 mm with thickness of 25 cm. The second basic layer of tarred ballast of 15 cm and a pavement of asphalt concrete of 4 cm were laid after the congestion;
- type 3 a base of a non-sized crushed slag with a layer thickness of 40 cm with the same two-layer pavement;
- type 4 a base of a sized crushed slag of the same grain metric composition with a layer thickness of 25 cm and the same two-layer pavement.

The module of elasticity of non-sized slag, determined by loading with a compressive plate of a 30 cm diameter is within 200–300 MPa.

Considerable amounts of open-hearth slag from the "Hemus" motorway with the necessary module of elasticity of 150 MPa, as the modules measured just after the road bases construction are considerably bigger.

The results of those first experiments to apply slag for base in road structures have turned to be unsuccessful due to the following reasons:

- non-keeping to requirements of the Bulgarian State Standard BSS 14610-78 and BSS 9341-78 for the open-hearth slag to stay on a slag dump for a minimum of a year until the chemical processes come down;
- the separation of metals from it and sizing to obtain a material of necessary grain metric have not been enough.

A number of experimental sections on the boulevards of Sofia were accomplished at the beginning of 1980's using open-hearth slag in the bituminous concrete pavement, for wearing-out and binder layers. The following types of structures can be distinguished:

- Type 1 – covering of two-layer asphalt concrete with an upper wear-out layer of 4 cm, binder of 5 cm and upper layer of the base of 10 cm of asphalt and open-hearth slag mixtures laid on crushed stone of 40 cm thickness;
- Type 2 – covering of a wear-out asphalt concrete layer of 4 cm crushed stone and binder of asphalt and open-hearth slag mixture of 10 cm laid on crushed stone of 40 cm thickness;
- Type 3 - covering of two-layer asphalt concrete as with type 2;
- Type 4 - covering of two-layer asphalt concrete: upper wear-out layer of 4 cm, binder of 5 cm and an upper layer of the base of 10 cm of asphalt and open-hearth slag mixtures laid on crushed stone of 40 cm thickness.

From the technical point of view, those attempts were successful but the use of slag gravel and sand in asphalt mixtures resulted in increased consumption of bitumen (about 1 - 1,5 %), which makes them economically ineffective for that purpose.

3.2. Slag from electric steel production

The production of this slag is connected with a modern method of steel production and its quantity will be increasing. At present in Bulgaria the main quantity of electric slag is produced in the town of Pernik, in "Stomana Industry", the so-called magnetically-sized slag. The volume of the slag produced annually is 50-55,000 t with a possibility of increase up to 110,000 t per year.

The main quantity of steel is produced in electric arc furnaces by the method of a process with oxidizing as this method gives a possibility to operate with higher contents of sulphur and phosphorus.

In the process of oxidation, after the metal mixture has been melted, the technology is divided into two periods: oxidizing and reducing. During the first one, the superfluous quantities of Si and Mn in the metal are oxidized, the contents of carbon are fixed to the necessary limits, the metal temperature is brought to 1640º C. The technology approved in many steel producing workshops is to take out the oxidizing slag after the basic quantities of phosphorus, manganese and silicon have been oxidized. After the first slag has been taken out, 1,0-1,5 % of the metal mass, freshly baked lime or chamotte are handed into the furnace aiming to form new oxidizing slag.

It is produced mainly in two fractions: from 0-40 mm and 80-200 mm, passing through crushing-and-separating equipment. It is used to make bases in road construction as an experimental section in the region of "Stomana Industry" was accomplished in 2006.

On the basis of the developed certificates for control, some tests of processed magnetically separated slag from steel electric furnace production of a fraction of 0-40 mm were accomplished.

The results of the analysis are presented in a kind of table and include:

Table 1

No	**No of the index under control**	**Unit of quantity**	**Method of index testing, standard, etc.**	**No of the sample**	**Results of testing (x* ± s)**	**Value and limit of an index; standard regulations or agreements**		
1	Stability of silicate disintegration after steam curing and treating with Na_2SO_4	% by mass	BSS 14610 - 78	Lab. No 1626	0.25	Class of slag		
						1	2	3
						≤ 5 ± no requirements	≤ 5 ± no requirements	≤ 5 ± no requirements
2	Stability of lime disintegration	% by mass	BSS14610 - 78	Lab. No 1626	0.2	1	2	3
						≤ 5 ± no requirements	≤ 5 ±no requirements	≤ 5 ± no requirements
3	Stability with iron and manganese break-up/disintegration	% by mass	BSS 14610 - 78	Lab. No 1626	Stable	1	2	3
						Stable		
4	Wear-out in a cylinder of Los Angelis type "	% by mass	BSS EN 1097 - 2:2000	Lab. No 1626	22,7	1	2	3
						≤ 20 ± no requirements	≤ 30 ± no requirements	≤ 45 ± no requirements
5	Crushing under	% by	BSS 172 - 83	Lab No	15,7	1	2	3

	static load	mass		1626		≤ 20 ± no require ments	≤ 25 ± no require ments	≤ 30 ± no require ments

The following tables present the results of the carried out chemical analysis of samples of origin from steel electric furnace production:

1 – sample – slag from EF (electric furnace)

2 – sample – slag from converter production, a new slag corridor

Table 2

No of the Sample	**Results of the analysis**							
	Fe	**FeO**	**CaO**	**MgO**	**SiO2**	**Al2O3**	**B = CaO + MgO\SiO2**	**pH**
	%	%	%	%	%	%		
1	0.35	31.58	30.81	6.05	11.2	3.19	3.29	9.5
2	0.21	32.35	29.06	4.18	13.75	3.51	2.43	2.43
Bulgarian State Standard	4423-79	4424-83	5036-73	5036-73	4425-80	4710-80		

3.3. Open-hearth slag

Its quantity is comparatively small. They are used mainly for road base analogously to blast slag. Such slag is available in slag dumps of "Stomana Industry" and "Kremikovtsi" AD. This method has not been used to produce steel since the beginning of 1970s.

Table 3 presents the physical-and-mechanical indices of slag samples taken from the slag dump.

Fraction, mm	**40**	**20 – 40**	**8 - 20**	**5 – 8**	**0 - 5**
Screen composition of the slag, %	16.9	22.9	29.9	14.6	15.6
Screen composition of the agglomerate, %	14.4	23.5	41.9	9.1	11.4

The wear-out of the cylinder of Los Angelis type characterizes slag as a material of good indices for road construction. The slag is processed and congested well. They are classified to the non-binding materials of good draining properties. That allows decreasing the road pavement bottoming.

The module of elasticity of non-sized slag is within 200 – 230 MPa.

The paper examines the possibility to use this slag to make embankments and bases. The firm slag is the one, which has stayed in a slag dump under the atmospheric conditions for more than a year. It can be used to build road embankments and pavements. To get good results with work, the following conditions should be kept: .the thickness of the layers put should be more than 50 cm, the frame density should not be less than 2,2 g/cm^3, each layer should be watered until its saturation of the embankment cavities with water. In this way, with a thickness of 40 - 45 cm, the bearing capacity of the road base is increased due to the water thermal mode.

The open-hearth slag can be used to build embankments of bigger height,12 - 15 m, and under bad hydrological conditions. They do not contain clay substances, have good draining properties and are insensitive to water. The module of elasticity is many times bigger (200 – 230 MPa) than the one required (30 MPa), which allows to build embankments of steeper slope.

The open-hearth slag that has stayed in a slag dump for more than a year is of great interest as a fraction in the bituminous layers in road pavements. However, this possibility has been still under clarification and tests in experiment sections are forthcoming.

3.4. Converter slag

There are about 50,000 t available at “Kremikovtsi” AD. This method of steel processing is not used..

The converter slag looks dark; some pieces are with a brownish shade. The presence of difference fractions is a precondition of good congestion of the mixture. .

On the basis of its good physical-an-mechanical properties the slag is a an appropriate material to make embankments and bases in road construction. With using slag, after its putting in the road structure, the bearing capacity can be increased by 1.5 – 2 times. That allows decreasing the thickness of the road structure, which makes it usable with building motorways as well.

3.5. Slag from non-ferrous metallurgy

The use of the slag obtained with the production of non-ferrous metals is of particular importance with using of the rough stocks of the country and environment..

The copper-production slag can be used in road construction. They have bulk density of 3.55 t/m^3, water-absorbing capacity of 0.1 – 0.2 %, compression strength of 100 MPa, good freezing resistance and small wear-out. The metal of the copper-production slag for all types of road bottoming and surfacing. It has a good cohesion with bitumen. Some sample sections of one-layer asphalt concrete pavement have

shown good behavior under the conditions of operation. The results obtained with building road pavement bottoming that is 27 cm thick, are also good.

The slag obtained from the production of lead and zinc can be used for mechanical stabilization of bases.

ENDNOTES

The use of metallurgic slag in road construction in Bulgaria has had traditions for more than 30 years. At present the main deductions are:

1. In connection with the increased requirements for the qualities of road building materials, it is necessary to update the standards used up to now. The direct harmonization with the EN is not a good approach because of the slag specific chemical composition determining the slag technical qualities.

2. The experience accumulated in using mainly one or two layers of different degrees of processing in the road basis is a basis of more common and differentiated usage of slag in much more loaded layers of the road basis.

The obtained thickness of slag layers of 40-50 cm create a better water-and-heat regime of the ground bed and lead to a certain increase of its bearing capacity by 10-15% for two years after the construction.

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BULGARIAN NATIONAL STANDARDS