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USE OF STEELWORKS CRUSHED SLAG IN ASPHALT MIXTURES USED TO ROADS

BY

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Abstract. In recent years studies regarding to environmental quality have shown that the steel industry is one of the industries whose activity involves significant consumption of natural resources and energy, is also generating waste that due to the valorification potential can be transformed into by-products.

This paper will present some experimental data on the development of asphalt mixtures with steelworks slag aggregate. With this aim recipes of asphalt mixtures were made (BA8, BA16), for which laboratory determinations were performed and have been set the main physical-mechanical properties of these mixtures.

The results of this analysis highlighted the real possibility of using these aggregates as building materials used in asphalt mixtures for roads and streets.

Key words: steelworks crushed slag; waste; asphalt concretes; physical-mechanical characteristics; optimal binder content.

1. Introduction

In recent years studies concerning the environmental quality have shown that the steel industry is one of the industries whose activity involves

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significant consumption of natural resources and energy, is also generating waste that due to the valorification potential can be transformed into by-products.

Experience has shown that recovery by recycling organic waste has both an ecological motivation as well as an economic motivation. Therefore, speaking about waste as a source of profit, should be considered both aspects: environmental and economic benefits.

It was found, especially in developed countries with concerns to limit the waste industry, the steelworks slag remaining after extraction of ferrous scrap, sorted and cleaned of impurities, can successfully replace natural aggregates specific to road construction works.

2. Laboratory Tests

Steelworks slag aggregates are used primarily in foundation layers or base layers of road structures, but can be used also in asphalt layers, replacing the classic chippings.

To support this information laboratory tests were made at the Faculty of Civil Engineering and Building Services of Iaşi, on two asphalt mixtures used mainly in technical class roads III ... V, namely BA8, BA16.

Aggregates that were used in the preparation of asphalt mixtures are natural and artificial aggregates, according to SR EN 13043-2003 and STAS 667-2000.

To achieve these asphalt mixtures recipes were needed the following sorts of aggregates: crushed slag aggregate 0...4 mm, crushed slag aggregate 4-8 mm, crushed slag aggregate 8...16 mm, natural sand 0...4 mm, limestone filler.

Given the granularity of each aggregate, wich results from laboratory tests, were established the proportion (in percents) of aggregates for achieving the asphalt recipes, according to Table 1.

Table 1
The Percentages of Aggregates Used to Produce Asphalt Mixes Recipes

Aggregate/Recipe, [%]	BA 8	BA16
Limestone filler	10.00	11.00
Natural sand 0...4 mm	12.00	9.00
Crushed slag aggregate 0...4 mm	35.00	28.00
Crushed slag aggregate 4...8 mm	43.00	28.00
Crushed slag aggregate 8...16 mm	–	24.00

The asphalt mixtures were prepared with a D50/70 bitumen, bitumen corresponding to the warm climatic zones - Annex A-SR174-1/2009, whose main characteristics are presented in Table 2.

Table 2
Bitumen Characteristics Used in the Preparation of Asphalt Recipes

Bitumen characteristics D50/70	Values obtained in the laboratory	SR EN12591-2009 (STAS 754-99)
Penetration at +25°C, 1/10 mm	66	66…70 (50…70)
Softening point (I.B.) °C	51.8	49…55 (46…54)
Penetration index, I.P.	–0.158	–1.5…+0.7

To establish the optimal dosage of binder were made Marshall type specimens with different dosages of bitumen, for which were determined the following characteristics:

a) asphalt mixture density;
b) water absorption;
c) Marshall stability;
d) swelling on Marshall specimens.

2.1. Determination of Asphalt Mixture Density

The determination is performed according to **SR EN 12697-6 /2004** – *Asphalt mixtures – Test methods for hot asphalt mixtures – Determination of the apparent mass volume of bituminous specimens.*

This test is used to determine the apparent mass volume of bituminous specimen after compaction. The method is applicable to specimens compacted in the laboratory.

The results of laboratory measurements are specified in Table 3.

Table 3
Density Values on the Marshall Specimens

Bitumen percentage %	Bitumen type	ρ_a kg/m^3
BA 8		
6.00	D 50/70	2.621
6.25		2.641
6.50		2.627
6.75		2.,640
BA 16		
5.00	D 50/70	2.629
5.25		2.654
5.75		2.696
6.00		2.691
6.25		2.680

2.2. Determination of Water Absorption

Determination of water absorption is performed according to SR EN 174 /1 -2009, Annex B – *Road works. Hot bituminous pavements. Technical requirements for asphalt mixtures.*

Water absorption is the amount of water absorbed by a specimen submerged in water for three hours at a vacuum of 15...20 mm Hg, and then for 2 hours in the same water at atmospheric pressure.

Volume absorption values are shown in Table 4.

Table 4

Values of Volume Absorption for Marshall Specimens

Bitumen percentage %	Bitumen type	ρ_a kg/m^3	Volume absorption %
BA 8			
6.00	D 50/70	2.621	3.530
6.25		2.641	2,913
6.50		2.627	2.152
6.75		2.640	1.036
BA 16			
5.00	D 50/70	2.629	4.823
5.25		2.654	2.395
5.75		2.696	1.316
6.00		2.691	1.250
6.25		2.680	0.929

2.3. Determination of Swelling on Marshall Specimens

Determination of swelling on Marshall specimens is performed according to STAS 1338-2-87 – *Hot asphalt mixtures and bituminous pavements made . Methods for determining and testing.*

The purpose is to determine the harmful influence of natural aggregates components sensitive to swelling, such as clay.

It is recommended to determine the swelling after three days storage in water, which allows a more sensible assessment of the materials. If swelling has elevated after three days, then the influence of inappropriate materials is extremely unfavourable. Swelling can take values up to 2.5% for asphalt mortars and for asphalt mixtures up to 2.0%.

Swelling values within 7, 14, 21 and 28 days on Marshall type specimens are shown in Table 5.

Table 5
Swelling Values on Marshall Type Specimens

Bitumen percentage %	Bitumen type	7 days	14 days	21 days	28 days	Recommended values
BA 8						
6.00	D 50/70	0.039	0.051	0.065	0.070	max 2.5%
6.25		0.041	0.045	0.067	0.071	
6.50		0.055	0.058	0.059	0.059	
6.75		0.050	0.054	0.063	0.068	
BA 16						
5.00	D 50/70	0.104	0.115	0.124	0.125	max 2.0%
5.25		0.080	0.102	0.118	0.130	
5.50		0.089	0.098	0.116	0.135	
5.75		0.140	0.140	0.141	0.142	
6.00		0.114	0.118	0.127	0.148	
6.25		0.125	0.128	0.139	0.149	

2.4. Determination of Marshall Stability

The determination is performed according to SR EN 12697-34+A1 – *Asphalt mixtures – Test methods for hot asphalt mixtures* . Marshall testing.

Specimens remain first 30...35 min in a water bath at a temperature of 60° ± 1°C.

Specimen is loaded immediately with a speed of 50 ± 3 mm/min. When the task indicated by the dial begins to decrease the trying is stopt. Maximum load indicated by the dial, expressed in daN, represents Marshall stability and deformation read on the microcomparator, expressed in 1/10 mm, represents the value of the flow.

Table 6
Marshall Stability Values S, Creep I, and the Ratio S/I

Bitumen percentage %	Bitumen type	*S*, [kN]	*I*, [mm]	*S*/*I* ratio kN/mm
BA 8				
6.00	D 50/70	12.1	3.42	3.54
6.25		13.1	3.62	3.62
6.50		14.9	4.44	3.36
6.75		12.6	5.04	2.50
BA 16				
5.00	D 50/70	12.1	3.45	3.51
5.25		10.5	4.38	2.39
5.75		14.1	5.74	2.46
6.00		14.7	5.86	2.51
6.25		14.7	6.41	2.29

Marshall stability values, *S*, creep, *I*, and the *S*/*I* ratio, of the series of asphalt mixtures prepared in the laboratory are presented in Table 6.

Physical-mechanical properties of asphalt mixtures prepared with non-paraffinaceous bitumen for roads must fall within the limits shown in Table 7.

Table 7

Required Values of Marshall Stability and Creep

Type of asphalt mixture	Bitumen type	Technical class of the road	Required values by SR 174-1/2009		
			S, [kN]	*I*, [mm]	*S*/*I* ratio
BA8	D50/70	IV	min 6.0	1.5.....4.5	1.3…4.0
BA16	D50/70	II… III	min 8.5	1.5.....4.0	2.0…6.3
		IV...V	min 6.5	1.5.....4.5	1.4…4.3

The optimum dosage of bitumen determined from laboratory tests and on Marshall samples are, at the lower end of the standard, or even below the indicative standard data (Table 8).

Table 8

Values of Bitumen Dosages after Laboratory Tests Results

Type of asphalt mixture	Bitumen dosages after laboratory tests results, [%]	Recommended bitumen dosage values STAS 174/1-2009, [%]
BA 8	6.25	6.5… 7.5
BA 16	5.75	6.5… 7.5

After establishing the optimal dosage of bitumen, asphalt specimens were made for determination the freeze–thaw phenomenon.

2.5. Asphaltic Specimens Testing at Freeze–Thaw Phenomenon

To determine the physical-mechanical properties of asphalt mixtures at the freeze-thaw phenomenon, recipes of asphalt mixtures were prepared in the laboratory with optimal bitumen dosage resulted in the laboratory. Test specimens resulted from asphalt mixtures: BA8, BA16.

Some of the samples were used to determine the freeze–thaw phenomenon at 28 days, while the other samples were witness samples that were tested in comparison at swelling, Marshall stability, creep index and the *S*/*I* ratio.

The first test samples were subjected to 28 freeze–thaw cycles in Atica TZ1 solution . This solution is a chemical fondant containing NaCl and molasses, solution prepared by the company “ATICA CHEMICALS SRL Ramnicu Valcea”.

The samples used were held during the freeze–thaw cycles for 10 hours at the positive (+18 ...+22°C) and 14 hours at negative temperatures (–21°C).

The results obtained at swelling, Marshall stability, flow index, *S*/*I* ratio, for the samples used in freeze–thaw action are presented in Table 9.

Table 9

Atica TZ1 Solution Treated Samples to 28 Days

Mixture	Atica TZ1 solution treated samples to 28 days			
	Swelling, [%]	Stability (*S*) at 60°C, [kN.mm]	Flow index (*I*) mm	*S*/*I* ratio kN/mm
BA8	0.090	10.1	3.75	2.69
BA16	0.196	10.8	4.31	2.50

Comparative measurements were made on control samples to determine swelling to 28 days, Marshall stability, flow index, *S*/*I* ratio. The results are presented in Table 10.

Table 10

Control Samples at 28 days (normal conditions)

Mixture	Control samples at 28 days			
	Swelling, [%]	Stability (*S*) at 60°C, [kN.mm]	Flow index (*I*) mm	*S*/*I* ratio kN/mm
BA8	0.075	12.5	4.29	2.91
BA16	0.149	10.8	3.73	2.89

Analysing the Tables 9 and 10, it can be concluded that aggregates of crushed slag from steelworks used to produce asphalt mixtures did not suffered significant changes after 28 freeze–thaw cycles. That means that the values of the swelling, Marshall stability and creep is substantially equal and after freeze–thaw action.

3. Conclusions

Use of steelworks slag aggregates in the road technology leads to numerous technical and economic advantages for both the user and the manufacturer namely

a) diversification of road construction materials;

b) reducing construction costs by replacing natural aggregates;

c) elimination of waste disposal dumps made from steel mills and therefore environmental protection;

d) properties of steelworks slag aggregates allow the road construction without affecting the environment by weather factors (rain, freezing-thawing.);

e) ensuring the service life of roads safe and comfortable, due to texture that provides roughness and high resistance to skidding.

In terms of laboratory testing can be concluded the following:

1. Percentages of steelworks slag aggregate used in asphalt mixtures making follow the recommendations of SR 174-2009.

2. Optimum binder content was determined taking into account asphalt mixture density, water absorption, stability and swelling of the Marshall specimens; resulted dosage in the preparation of bituminous asphalt mixtures with steelworks slag aggregate is generally lower than the recommended dosage for a classical mixture.

3. Bulk density of the asphalt mixture varies between 2.6 and 2.7 kg/m^3, being higher than the bulk density of a classical mixture. The difference is made by the higher density of steelworks slag aggregates compared to the density of natural aggregates.

4. Swelling values determined on Marshall specimens at intervals of 7, 14, 21 and 28 days are lower than the maximum required.

5. In the laboratory tests for determining Marshall stability can be observed that the values of stability, *S*, creep, *I*, and the *S*/*I* ratio is less than the maximum imposed by the standard.

6. After the 28 freeze–thaw cycles, it was found that the differences between a witness mixture with steelworks slag aggregates and a mixture with steelworks slag aggregates treated with a solution of Attica TZ1, does not present significant differences in terms of swelling and Marshall stability.

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UTILIZAREA ZGURII CONCASATE DE OȚELĂRIE ÎN MIXTURILE ASFALTICE FOLOSITE LA DRUMURI

(Rezumat)

Studiile realizate în ultimul timp privind calitatea mediului, au evidențiat faptul că industria siderurgică fiind una din ramurile industriale a căror activitate presupune

consumuri importante de resurse naturale şi de energie, este în acelaşi timp şi generatoare de deşeuri care datorită potențialului de valorificare pot fi transformate în subproduse.

Se prezintă câteva date experimentale, cu privire la realizarea de mixturi asfaltice cu agregate din zgură de oțelărie. Pentru aceasta s-au realizat două rețete de mixturi asfaltice (BA8, BA16), pentru care s-au efectuat determinări de laborator şi s-au stabilit principalele proprietăți fizico-mecanice ale acestora.

Rezultatele analizelor au subliniat posibilitatea reală de a folosi aceste agregate ca materiale de construcții în mixturile asfaltice pentru drumuri şi străzi.