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THE PHYSICAL-MECHANICAL CHARACTERISTICS OF THE ASPHALT MIXTURES FOR BITUMINOUS COATINGS PREPARED WITH A HIGH BLAST FURNACE GRANULATED SLAG FILLER FROM THE LIBERTY GALATI PLANT, ROMANIA

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Abstract

Asphalt mixtures used for bituminous coatings consists of a homogeneous, compact mixture of natural aggregates agglomerated with bitumen. Replacing the natural filler with an artificial one, obtained as waste in the metallurgical industry, would lead to a saving of material and financial resources, being one of the methods of environmental conservation by conserving the relief, protecting localities from noise produced in stone quarries, reusing a waste material. The processing of granular blast furnace slag from Liberty Galati plant, country of Romania, into filler and their subsequent use in the preparation of asphalt mixtures, leads to obtaining favourable results on two of the most currently used types, AC16surf50/70 and AC22.4bin50/70.
The appreciation of the behaviour of the asphalt mixture prepared with blast furnace slag filler compared to a standard, leads to the conclusion that the mixture is correctly dimensioned and will withstand physical and mechanical factors.

Keywords: Asphalt Mixture, Blast Furnace Slag Filler.

Introduction

The bf slag has the ability to be used as construction material in Romania, considering the specifications of Directive 89/106/EEC on the harmonisation of the laws, technical regulations and administrative specifications of the Member States relating to products for constructions, the considerations of Ordinance 20/18.08.2010 on the establishment of measures for the uniform application of EU legislation harmonising the conditions for the marketing of products, as well as the specifications of HG 622/2004 with amendments and subsequent additions on the establishment of the conditions for placing construction products on the market. BF slag is produced in the Liberty Galati plant and meets the characteristics of building materials according to specifications of EN 13043:2002/AC:2004. BF slag is an artificial aggregate that can replace natural aggregates in the process of obtaining raw materials for construction industry. It is very commonly found at foundation works of various infrastructure works. As for the source of provenance, the bf slag is obtained in the metallurgical industry, at the SC Liberty Galati steel plant, located in south-eastern Romania, in the city of Galati. Currently, the bf slag storage dump of the plant is in Galati municipality, on its own storage platform. SC Liberty Galati exploits the bf slag, performing the processes of extraction, selection of slag from storage dump, granulating it in different size fractions, storage of the materials of different size fractions obtained until revaluation. Used as a construction material, favourable effects will be obtained as reducing or even removing the dimensions of the storage dump, conservation of natural resources by limiting their use in industry (natural aggregates from quarries) and by redesigning the materials commonly used in construction works infrastructure, inclusion in the waste management plans of the slag new methods for revaluation.

The Characteristics of The Blast Furnace Slag Obtained at SC Liberty Galati

The characteristics of the bf slag obtained at SC Liberty Galati, from which it is desired the processing and obtaining of filler in the laboratory, are stated in the certificate for factory production control in accordance with the provisions of EN 13043:2013 ‘’Aggregates for bituminous mixtures and surface finishing, used in the construction of roads, airports and other traffic areas’’. Below, in table 1, are shown the characteristics of the slag.

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Crt. No.	Characteristics	Results
1	Bulk density (for fraction 0/63 mm)	1,51 Mg/mc
2	Pre-dried volumetric mass for fraction 0,063 / 31,5 mm	2,58 Mg/mc
3	Freeze-thaw resistance - for fraction 4/8 mm - for fraction 8/16 mm - for fraction 16/31,5 mm - for fraction 31,5/63 mm	 2,6 % 1,9 % 0,7 % 0,9 %
4	Chemical composition - calcium oxide, CaO - silicon dioxide, SiO_2 - aluminium oxide, Al_2O_3 - iron oxide, FeO - magnesium oxide, MgO - manganese oxide, MnO - sulphur in the form of sulphides, S	 34,0...46,0 % 31,0 ... 39,0 % 11,00 ... 21,00 % 0,2 ...0,7 % ≤ 8 % 0,1… 1,9 % 0,4…1,0 %
5	Chemical character (determination made by SC Liberty Galati supplier)	the raw material is chemically inert, it is 100% ecological, it has no negative impact on the environment
6	Disintegration of granulated slag from the furnace, made on the 0/63 mm lot, cooled in air from the dump (determination made by the SC Liberty Galati supplier)	after immersion in water, no piece shows cracks or disintegrations

Table 1: Characteristics Determined on Blast Furnace Slag

Visually analysing the raw material, the conclusions are the raw material is homogeneous, with a compact granular appearance, crystalline, without any impurities of any kind (such as: earth bulbs, coal, clays, etc.). The granules have a polyhedral appearance, they have sharp edges, and have different dimensions included in the 0/4 mm granulation. The material is chemically inert, 100% ecological, does not have a negative impact on the environment.

The Characteristics of The Blast Furnace Slag Filler Obtained in Laboratory

To use the filler in the preparation of asphalt mixtures, we determined the conformity of the bf slag filler with the requirements of the standard SR EN 13043. The bf slag was grinded into filler in laboratory, from 0/4 mm fraction of granulated slag, and the determined characteristics are shown in table 2.

Crt. no.	Characteristics	Tests carried out	Results
1	Fineness / size and density of granules	Granularity	- passing through sieve of 2 mm: 100 % - passing through sieve of 0,125 mm: 87,9 % - passing through sieve of 0,063 mm: 76,3%
		Blaine test	5086 cm^2/g
		Pre dried volumetric mass	2,589 Mg/m^3
2	Purity	Harmful fine particles (Methylene blue test)	0,4 g solution of methylene blue/ kg of granular fraction of 0/0,2 mm.
3	Solubility in water	Solubility in water	0,6%
4	Emission of hazardous substances	Identification of raw material	artificial rock made of granular slag from the furnace, chemically inert, free of emissions and hazardous substances. Chemical composition [1]: - calcium oxide, CaO 34,0...46,0 % - silicon dioxide, SiO_2 31,0 ... 39,0 % - alumina, Al_2O_3 11,00 ... 21,00 % - iron oxide, FeO 0,2 ...0,7 % - magnesium oxide, MgO ≤ 8 % - manganese oxide, MnO 0,1… 1,9 % - sulphur in the form of sulphides, S 0,4…1,0 %
5	Disintegration by cooling	Disintegration of particles	After immersion in water, no pieces show

	in air		cracks or disintegration.
6	Durability on freeze-thaw	Freeze-thaw resistance on coarse aggregates - on 4/8 mm - on 8/16 mm - on 16/31,5 mm - on 31,5/63 mm	 2,6 % 1,9 % 0,7 % 0,9 %
7	Filler-binder interaction	Hydrophilicity coefficient	0,785

[1)]According to the test results declared by the producer, Liberty, County of Galati, Romania.

Table 2: Characteristics Determined on Blast Furnace Slag Filler

Asphalt Mixture Prepared with Blast Furnace Slag Filler

To design an asphalt mixture recipe, respectively to establish the best proportions of the component materials to obtain the best characteristics of these elements, it is necessary to analyse the component materials in view of their property of both mineral aggregates and of the binder influences differently. The components of the asphalt mixture will be analysed first, to consider all the premises of the study elaboration.

1. Mineral aggregates

The mineral aggregates used to obtain the asphalt mixtures come from stone quarries (crushed chipping) and crushed sand (from gravel pit). In general, quarry aggregates are used on technical class I-III roads (high-traffic roads such as highways, express roads, national roads).

In the present study, mineral aggregates from the Suseni quarry of andesite - Harghita county in Romania and natural sand from the Tupilati gravel pit - Neamt Romania county will be used. The characteristics of the aggregates are shown in tables no. 3 below.

Crt. no.	Characteristics /results	Grade 0/4 mm	Grade 4/8 mm	Grade 8/16 mm	Grade 16/22,4 mm
1	The rock of origin	Magmatic rock, andesite type			
2	Granularity declared by the producer (Passing % through sieve of ... mm) 22,4 16 8 4 2 0,125 0,063	 - - - 98,1 65,8 11,3 1,8	 - 100 98,5 5,9 0,2 - 0,0	 100 93,9 3,0 - - - 0,0	 92,7 5,5 0,1 - - - 0,0
3	Sand equivalent, SE	70,2 %	-	-	-
4	Evaluation of fine particles, MB	2,5 g/kg	-	-	-
5	Particle shape (flattening coefficient)	-	17,4 %	13%	7,3%
6	Particle shape (shape index)	-	15,1%	10,2%	6,3%
7	Granule density and water absorption - density of oven dry granules - density of saturated and dry surface granules - bulk density of granules - water absorption of granules.	 2,676 Mg/m^3 2,715 Mg/m^3 2,783 Mg/m^3 1,434 %	 2,663 Mg/m^3 2,708 Mg/m^3 2,788 Mg/m^3 1,676%	 2,657 Mg/m^3 2,707 Mg/m^3 2,796 Mg/m^3 1,860 %	 2,674 Mg/m^3 2,713 Mg/m^3 2,785 Mg/m^3 1,485 %
8	Resistance to Los Angeles crushing (on 10/14 mm fraction)	-	-	16,3 %	-
9	Resistance to micro-Deval wear (on 10/14 mm fraction)	-	-	14,2 %	-

10	Crush-strength impact method (on 10/14 mm fraction)	-	-	8,67%	-
11	Freeze-thaw resistance, F	-	0,6%	0,3%	0,2%
12	Magnesium sulphate test (on 10/14 mm fraction)	-	-	5,4%	

Table 3: Characteristics Determined on Aggregates Used for Asphalt Mixture Design

2. Bitumen

To obtain an asphalt concrete, this being a mixture of agglomerated mineral materials with a bituminous binder, we used petroleum bitumen for roads, non-paraffin, class 50/70 .

Bitumen is the one that binds the aggregate granules by filming, it is the one that fills the gaps between the granules and maintains the compact structure of the whole mixture. In the mineral structure, the bitumen is filerized by the added filler, so that the adhesion to the bitumen-filler interface is as high as possible. Also, by filerizing the bitumen, a decrease in the bitumen content in the asphalt is obtained. The characteristics of the bitumen used in this study are shown in table no. 4.

Crt. no.	Characteristics	Results
1	Bitumen type	non-paraffin, class 50/70
2	Penetration, 1/100 mm	60
3	Softening point, °C	50
4	Fraass breaking point, °C	Below -10

Table 4: Characteristics of The Bitumen

3. Filler

Added to the asphalt mixture, the filler will influence its properties, such as:
- stability and creep of asphalt mixtures which vary significantly with filler dosage.
- improves the viscosity of the binder, this being given primarily by its granularity.
- reduces the volume of gaps in the asphalt mixture.

To appreciate the asphalt mixture characteristics designed with filler made from bf slag, the aim is to prepare and test different types of asphalt mixtures, both with standard limestone filler, the most used in asphalt mixtures, and with bf slag filler, and to compare the results both with each other and with the provisions of the applicable standards. Properties of two fillers used to carry out the tests are shown in table 5.

Crt. no.	Characteristics	Results on bf slag filler	Results on limestone filler
1	Granularity	- passing through sieve of 2 mm: 100 % - passing through sieve of 0,125 mm: 87,9 % - passing through sieve of 0,063 mm: 76,3%	- passing through sieve of 2 mm: 100 % - passing through sieve of 0,125 mm: 93,2 % - passing through sieve of 0,063 mm: 80,21%
	Blaine test	5086 cm^2/g	4276 cm^2/g
	Pre-dried volumetric mass	2,589 Mg/m^3	2,750 Mg/m^3
2	Harmful fine particles on 0/0,2 mm fraction (Methylene blue test)	0,4 g solution of methylene blue/ kg.	2,0 g solution of methylene blue/ kg.
3	Solubility in water	0,6%	0,17%
4	Identification of raw material	artificial rock made of granular slag from the furnace, chemically inert, free of emissions and hazardous substances.	natural rock made of limestone.
	Chemical composition: - calcium oxide, CaO - silicon dioxide, SiO_2 - alumina, Al_2O_3 - iron oxide, FeO - magnesium oxide, MgO - manganese oxide, MnO - sulphur in the form of	 34,0...46,0 % 31,0 ... 39,0 % 11,00 ... 21,00 % 0,2 ...0,7 % ≤ 8 % 0,1… 1,9 % 0,4…1,0 %	 51,54% 4,25% 1,67 % 0,47 % 0,10% - 0,09%

	sulphides, S		
5	Disintegration of particles	After immersion in water, no pieces show cracks or disintegration.	-
7	Hydrophilicity coefficient	0,785	0,785

Table 5: Characteristics of bf Slag Filler Compared to a Limestone Filler, Used for Asphalt Mixture

The Use of Mineral Aggregates in Asphalt Mixtures

The scope of this study was to prepare two types of asphalt mixture used in surface course and binder course in which the type of filler differs and to appreciate the results by comparison. The types of mixtures are:

AC 16surf50/70 and AC22.4bin50/70 standard - asphalt concrete with chipping and limestone filler - hereinafter referred to as standard asphalt mixtures.

AC 16 surf50/70and AC 22.4bin50/70 with bf slag filler - asphalt concrete type with chipping and slag filler - hereinafter referred to as asphalt mixtures with slag filler.

They were prepared with the dosage of optimum aggregates composition and three dosages of bitumen as followings:

I. AC 16surf50/70 standard for surface course, three series, at which the bitumen dosage differs: 5.7%, 5.9% and 6.1%, respectively.
II. AC22.4bin50/70 standard for binder course, three series, at which the bitumen dosage differs: 4.3%, 4.5% and 4.7%, respectively.
III. AC16surf50/70 with bf slag filler for surface course, three series, at which the bitumen dosage differs: 5.7%, 5.9% and 6.1%, respectively.
IV. AC22.4bin50/70 with bf slag filler for binder course, three series, at which the bitumen dosage differs: 4.3%, 4.5% and 4.7% respectively.

The tests performed was on Marshall samples made in laboratory. Performance based requirements are:

a) Bulk density

Asphalt mixture type	Binder dosage series, %	Bulk density on standard mixtures, g/cm^3	Bulk density on bf slag filler mixtures, g/cm^3
AC16surf50/70	5,7	2,324	2,370
AC16surf50/70	5,9	2,333	2,388
AC16surf50/70	6,1	2,382	2,368
AC22,4bin50/70	4,3	2,346	2,285
AC22,4bin50/70	4,5	2,374	2,301
AC22,4bin50/70	4,7	2,384	2,328

Table 6: Bulk Density on Standard Mixture and With bf Slag Filler Mixture

b) Water absorption

Asphalt mixture type	Binder dosage series, %	Water absorption on standard mixture, % vol.	Water absorption on bf slag filler mixtures, % vol.
AC16surf50/70	5,7	2,793	2,062
AC16surf50/70	5,9	1,694	1,923
AC16surf50/70	6,1	0,953	1,220
AC22,4bin50/70	4,3	3,856	4,691
AC22,4bin50/70	4,5	2,647	4,337
AC22,4bin50/70	4,7	2,461	3,555

Table 7: Water Absorption on Standard Mixture and with bf Slag Filler Mixture

c) Marshall test

c.1) Marshall stability

Asphalt mixture type	Binder dosage series, %	Marshall stability on standard mixture, KN	Marshall stability on bf slag filler mixtures, KN
AC16 surf 50/70	5,7	13,16	9,04
AC16 surf 50/70	5,9	8,42	9,48
AC16 surf 50/70	6,1	9,67	9,25

AC 22,4 bin 50/70	4,3	6,03	4,93
AC 22,4 bin 50/70	4,5	9,20	9,14
AC 22,4 bin 50/70	4,7	7,91	7,48

Table 8: Marshall Stability on Standard Mixture and with bf Slag Filler Mixture

c.2) Marshall flow

Asphalt mixture type	Binder dosage series, %	Marshall flow on standard mixture, mm	Marshall flow on bf slag filler mixtures, mm
AC16 surf 50/70	5,7	4,26	4,03
AC16 surf 50/70	5,9	4,69	3,76
AC16 surf 50/70	6,1	5,18	4,11
AC 22,4 bin 50/70	4,3	4,27	2,93
AC 22,4 bin 50/70	4,5	4,21	2,99
AC 22,4 bin 50/70	4,7	3,54	3,82

Table 9: Marshall Flow on Standard Mixture and with bf Slag Filler Mixture

c.3) Rigidity

Asphalt mixture type	Binder dosage series, %	Rigidity on standard mixture, KN/mm	Rigidity on bf slag filler mixtures, KN/mm
AC16 surf 50/70	5,7	3,09	2,24
AC16 surf 50/70	5,9	1,80	2,52
AC16 surf 50/70	6,1	1,87	2,25
AC 22,4 bin 50/70	4,3	1,41	2,68
AC 22,4 bin 50/70	4,5	2,19	3,06
AC 22,4 bin 50/70	4,7	2,24	1,96

Table 10: Rigidity on Standard Mixture and with bf Slag Filler Mixture

d) Swelling in the water after 7 days, 15 days, 21 days, 28 days.

Asphalt mixture type	Binder dosage series, %	Swelling in the water, % at			
		7 days	14 days	21 days	28 days
AC16 surf 50/70 standard	5,7	0,00	0,00	0,00	0,00
AC16 surf 50/70 standard	5,9	0,00	0,00	0,00	0,00
AC16 surf 50/70 standard	6,1	0,00	0,00	0,00	0,00
AC 22,4 bin 50/70 standard	4,3	0,00	0,00	0,00	0,00
AC 22,4 bin 50/70 standard	4,5	0,00	0,00	0,00	0,00
AC 22,4 bin 50/70 standard	4,7	0,00	0,00	0,00	0,00
AC16 surf 50/70 with slag filler	5,7	0,00	0,00	0,00	0,00
AC16 surf 50/70 with slag filler	5,9	0,00	0,00	0,00	0,00
AC16 surf 50/70 with slag filler	6,1	0,00	0,00	0,00	0,00
AC 22,4 bin 50/70 with slag filler	4,3	0,00	0,00	0,00	0,00
AC 22,4 bin 50/70 with slag filler	4,5	0,00	0,00	0,00	0,00
AC 22,4 bin 50/70 with slag filler	4,7	0,00	0,00	0,00	0,00

Table 11: Swelling in The Water on Standard Mixture and with bf Slag Filler Mixture

Conclusion

The samples were made in the laboratory, based on well-established and precisely dosed mixtures. The values obtained comply with the provisions of current technical regulations, which leads us to assess their quality, up to this point of testing, as compliant. The variations of the obtained results concern:

- The density of the mixtures increases as the binder dosage increases.
- Water absorption decreases as the binder dosage increases.
- Stability increases as the binder dosage increases.
- The creep increases as the binder dosage increases.

Analysing in parallel the standard asphalt mixtures and those prepared with bf slag filler, the same tendency of increasing/decreasing the characteristic values can be observed, along with the variation of the binder dosage.

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