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STUDIES ON THE INFLUENCE OF THE TYPE OF AGGREGATES AND THE TYPE OF BITUMEN ON THE PERFORMANCE OF AIRPORT ASPHALT MIXTURES

Petcu Claudia, Ph.D. Eng. Lecturer, Technical University of Civil Engineering of Bucharest, Romania, e-mail: claudia.petcu@utcb.ro
Răcănel Carmen, Ph.D. Eng. Professor, Technical University of Civil Engineering of Bucharest, Romania, e-mail: carmen.racanel@utcb.ro

Abstract

Among the component materials of a flexible or mixed road structure, the asphalt mixture is considered to be the most important material to be accurately characterized. Most of the literature references on aggregates in asphalt mixtures have paid attention to the grading curve, shape, strength and roughness, all of which are important for the performance of asphalt mixtures. The modification of bitumen with polymers gives certain qualities to the asphalt mixtures containing it, namely: high temperature elastic properties, thermal cracking resistance, fatigue resistance, and long-term durability. The aim of this paper is to present the influence of the aggregate type and bitumen type on the physico-mechanical characteristics of asphalt mixtures.The laboratory studies were carried out in the Road Laboratory on the asphalt mixture BAA 16 (AC16) used in the wearing course of airports. Tests were carried out, such as the Marshall set and flow index, water absorption, stiffness modulus, fatigue resistance, resistance to permanent deformation, fuel resistance.The quality of the materials used in an asphalt mixtures plays an important role in the subsequent in-service behavior of the asphalt mixture.

Keywords: aggregates, bitumen, asphalt mixture, airport

1. INTRODUCTION

In recent decades, road administrations around the world have become aware of the importance of prolonging the life cycle of asphalt mixtures included in various layers of road structures (Maia et al.,2021).

It is important and urgent to increase the sustainability of these materials in order to reduce the natural resources that are expended for their construction, maintenance and rehabilitation. This is why it is important to study the performance of asphalt mixtures and implicitly of its constituents, taking into account the characteristics of the works and of the materials available in each region.

Asphalt mixture, is a fundamental component of road construction, it plays an essential role in the service life and bearing capacity of roads (Lu and Isacsson,1997).Due to the limitations of unmodified asphalt mix, polymer modified bitumen asphalt mix has been proposed to achieve superior performance [Polacco et al., 2006].

Researchers have suggested that the stiffness modulus can serve as an index for evaluating the fatigue performance of asphalt mixtures. For example, when the modulus decreases to 50% of its initial value during fatigue testing of asphalt material, the material is considered fatigued (Wei et al., 2024). However, some researchers argue that reducing the stiffness modulus to 50% of the initial value may not fully represent the fatigue failure criterion for asphalt mixtures, proposing that a reduction of 65% or in the range of 15-25% of the initial value would be more appropriate (Hartman and Gilchrist, 2004; Lou et al., 2021). Currently, researchers are improving the fatigue performance of asphalt mixtures mainly by modifying the component materials (Chen et al., 2020).

As Zhang et al. explain (Zhang et al., 2020), bitumen is usually acidic, so when mixed with acidic aggregates, some repulsive interactions occur that promote partial bonding in which there are only a few hydrogen ions. The stripping phenomenon in asphalt mixtures is one of the most important types of distress in flexible pavements (Mehrara and Khodaii, 2013). Usually, the affinity between aggregates and bitumen is described by four theories, isolated or combined (Cui et al., 2014): molecular arrangement, mechanical adhesion, surface energy and chemical reaction. Several factors affect these theories, namely: the chemical composition of the materials; the viscosity of the bitumen; the texture, angularity, shape, porosity, and cleanliness of the aggregates; the surface tension at the bitumen-aggregate interface; and the temperature during mixing or the presence of moisture.

Although Aguiar-Moya et al. (Aguiar-Moya et al., 2018) stated that an increase in aggregate-binder strength may not improve the water resistance of bituminous mixtures, other authors, such as Hamedi et al. (Hamedi et al., 2021), Cui et al. (Cui et al., 2014) and Lucas Júnior et al. (Lucas Júnior et al., 2021), reported that better water and fatigue resistance can be obtained by introducing adhesion promoters into their compositions.

Zhang et al. (Zhang et al., 2015) investigated the influence of the mineralogical composition of four aggregates (two of which are granitoids) and two unmodified binders on the water resistance of the aggregate-bitumen bond. They observed a good correlation between aggregate mineralogical composition and moisture absorption, as well as a greater influence of the geological nature of the aggregate (than the type of binder) on moisture sensitivity. Yin et al. (Yin et al., 2017) have studied the influence of the chemical compositions of some aggregates on the quality of the bitumen-aggregate interface, after demonstrating (in the case of granite) that this bond is only guided by its physical adhesion to the binder. In another study, Feng et al. (Feng et al., 2020) also evaluated the mineral compositions of different aggregates, in addition to their surface texture, concluding that these properties have a significant impact on the behavior of the bitumen-coarse aggregate interface.

Another approach to increase the overall cracking resistance of the pavement is to create anti-cracking characteristics of the asphalt mixture (Chomicz-Kowalska, 2017). This can be achieved by various means: by selecting a certain type of binder and its amount, the type and grain size of the mixture . of aggregates and also by incorporating various additives in the binder or in the asphalt mixture as a whole, for example polymers, recycled rubber recycled rubber, fiber or natural bitumen (Iwanski et al., 2016).

The physical and chemical properties of aggregates are known to influence the performance of asphalt mixes. For example, many studies emphasize the role of aggregate shape in controlling the performance of asphalt mixtures, especially resistance to fatigue cracking and rutting (Masad et al., 2007). These studies conducted experiments that focused on the influence of fine aggregate, coarse aggregate, or the combined effect of fine and coarse aggregate on the mechanical properties and performance of asphalt mixtures.

The effect of softening point of a binder on resistance to permanent deformation of bituminous pavement mixes has been studied by various researchers. An example is hot rolled asphalt where it was found that the rate of rutting in the wheel tracking test at 45°C, was halved by increasing softening point by approximately 5ºC (Bing et al., 2006).

Bitumen ductility is a measure of its capacity to elongate or stretch and it is an indication of the material to flow.

Viscosity is synonymous with internal friction and is a measure of the resistance to flow.

The bitumen viscosity of bitumen shows a complex response under different conditions and it influences the mixing, laying and compaction of asphalt mixtures as well as the pavement performance (Xiaohu and Ulf, 1997). In view of these reasons viscosity, penetration, softening point and ductility measurements have been used to classify bitumen, but due to the visco-elastic nature of bitumens the results lack uniformity as the bitumen source and molecular content might differ (Edwards and redelius, 2003).

The objective of this research is to investigate the effect of aggregate type and bitumen type on the physico-mechanical properties of airport asphalt mixtures. This case study can contribute to a better design of airport asphalt mix networks. The possibility to maximize the performance of the materials within an asphalt mix design will facilitate the use of flexible/semi-rigid structures on airport surfaces.

Three asphalt mixtures were tested, using two types of aggregate and two types of bitumen. The physico-mechanical performance of the three asphalt mixtures was also determined in terms of Marshall test, water absorption, stiffness modulus, resistance to permanent deformation - cyclic compression test, fatigue and fuel resistance.

This paper describes in detail all the materials used in the above-mentioned research; the preparation of the samples; the test equipment, its configuration and procedures; as well as the results obtained and some conclusions that can be drawn.

The objective of this research is to establish the influence of aggregates type and bitumen type of airport asphalt mixtures according to European Standards SR EN 12697-30, SR EN 12697-34, SR EN 12697-6, SR EN 12697-26, SR EN 12697-24, SR EN 12697-25 and SR EN 12697-43.

2. MATERIALS AND METHODS

The recipe is designed for an asphalt mixture used in wearing course of an airport pavement; the mixture has 16 mm nominal maximum size.

The bitumen is PmB one: 45/80-65 and 45/80 Fr (PmB 45/80-65 additivated for low viscosity and resistance to fuel). The bitumen characteristics used are presented in Table 1.

Table 1. Bitumen characteristics

Characteristic	Bitumen 45/80-65	Bitumen 45/80 FR
Penetration at 25ºC (0.1mm)	45-80	30-70
Softening point (ºC)	≥ 65	≥ 80
Force ductility (J/cm^2)	≥ 3 (5ºC)	-
Viscosity at 135ºC (Pa.s)	1.3	1.225

The aggregates are from Revărsarea and Turcoaia quarries. The aggregates characteristics used are presented in Table 2.

Table 2. Aggregates characteristics

Characteristics	Revărsarea quarrie			Turcoaia quarrie		
	sort 0/4	sort 4/8	sort 8/16	sort 0/4	sort 4/8	sort 8/16
Bulk density (kg/m^3)	1610	1370	1410	1495	1371	1414
Resistance to fragmentation Los Angeles	-	16	12	15.2	15.8	17.6
Resistance to freezing and thawing (%)	-	0.6	0.9	-	0.1	0.1
The content fines part (%)	-	0.2	0.1	0.62	0.2	0.14
Shape index (%)	-	22.2	17.9	-	29	13

The used materials and recipes of asphalt mixture BBA16 are: aggregates from Revărsarea: recipe A and recipe B: 20.2% sort 8/16, 20.8% sort 4/8, 50% sort 0/4; aggregates from Turcoaia: recipe C: 19.2% sort 8/16, 26.8% sort 4/8, 46% sort 0/4; limestone filer from Holcim: 9% for recipe A and B, 8% for recipe C; bitumen from OMV, 5.4% type 45/80 Fr (recipe A and C) 5.4% type 45/80-65 (recipe B).

The gradingc curves for designed mixture recipes are presented in Figure 1.

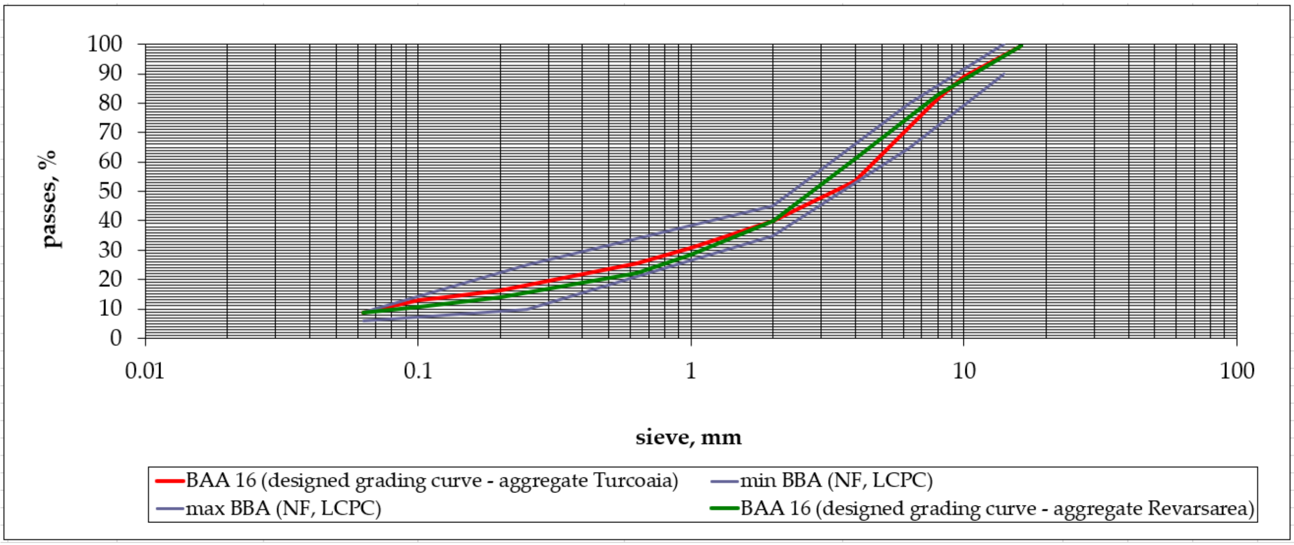

Figure 1. Grading curves for designed mixture recipes

After compaction of specimens (using the European standards EN 12697-30 [40] for cylindrical specimens), the studied bituminous mixtures were submitted to the mechanical performance assessment tests described below. The tests were conducted on Marshall samples made at 50 blows. The results represent four determination average. Marshall Test was made according to European Standard SR EN 12697-34. The results obtained from Marshall stability and flow for the recipes A, B, C are presented Figure 2. and Figure 3.

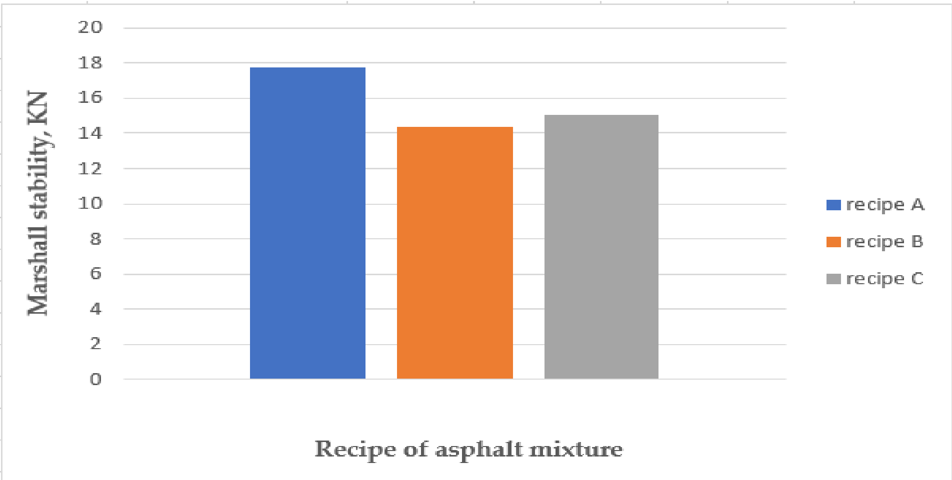

Figure 2. Marshall Stability versus recipe of asphalt mixture

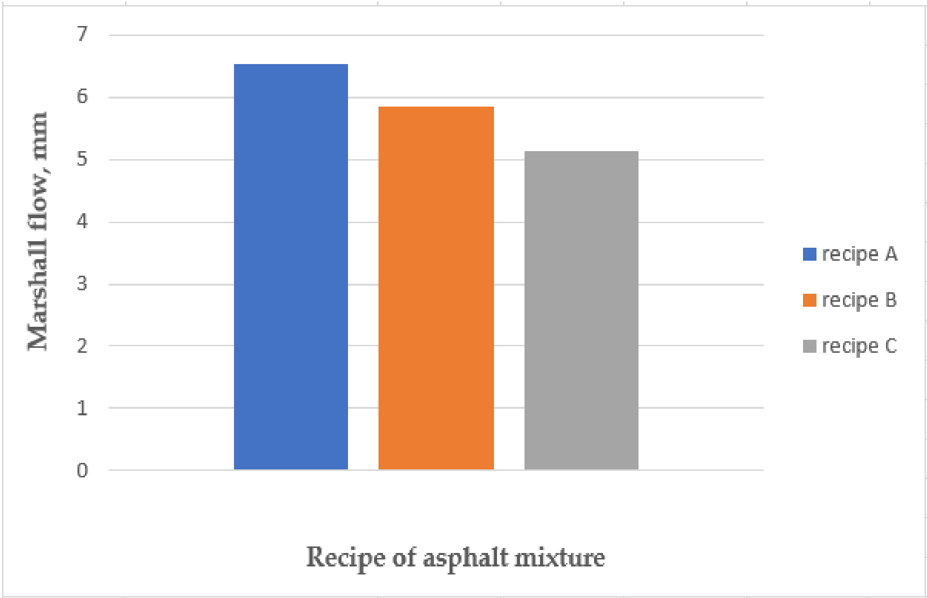

Figure 3. Marshall Flow versus recipe of asphalt mixture

Marshall stability is 23% greater for recipe A than recipe B and 18% greater than recipe C. Marshall flow index is 12 % greater in case of recipe A than recipe B and 27% greater than recipe C.

The bulk density was determined according to SR EN 12697-6, metoda B and water absorption according to Annex B of AND 605-2016.

To determine the bulk density, the dry mass of the specimen and the density of water at the test temperature were determined. The specimen was immersed in the water bath and allowed to saturate to constant mass. The mass of the saturated, submerged specimen and then the apparent density in the saturated, dry-surface saturated state were then determined.

The water absorption is the amount of water absorbed by the accessible voids from of a test specimen immersed in water for three hours at a vacuum of 15...20 mm column of mercury, then two hours in the same water at normal pressure. Water absorption is expressed as a percentage of the volume or mass of the specimen tested

The bulk density is presented in Figure 4. and water absorption in Figure 5.

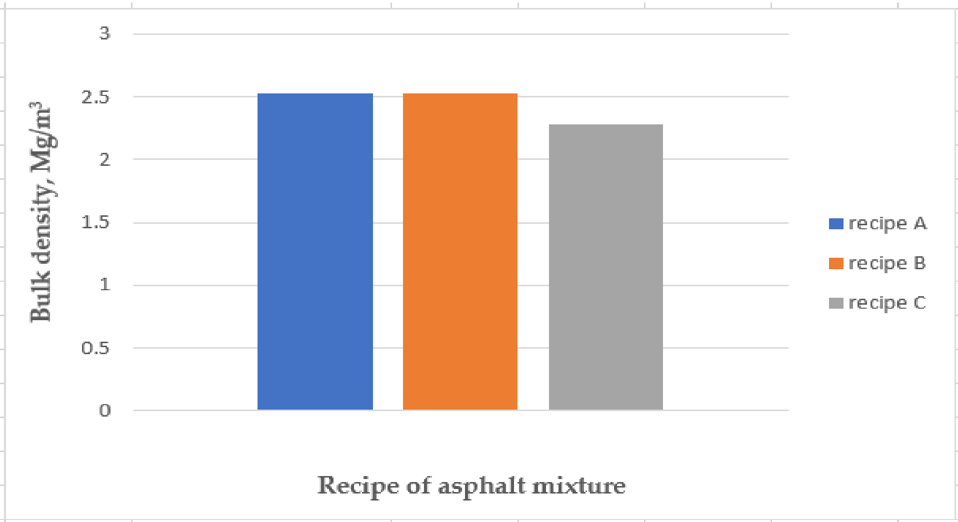

Figure 4. Bulk density versus recipe of asphalt mixture

Bulk density is 11 % greater in case of recipe A and B than recipe C.

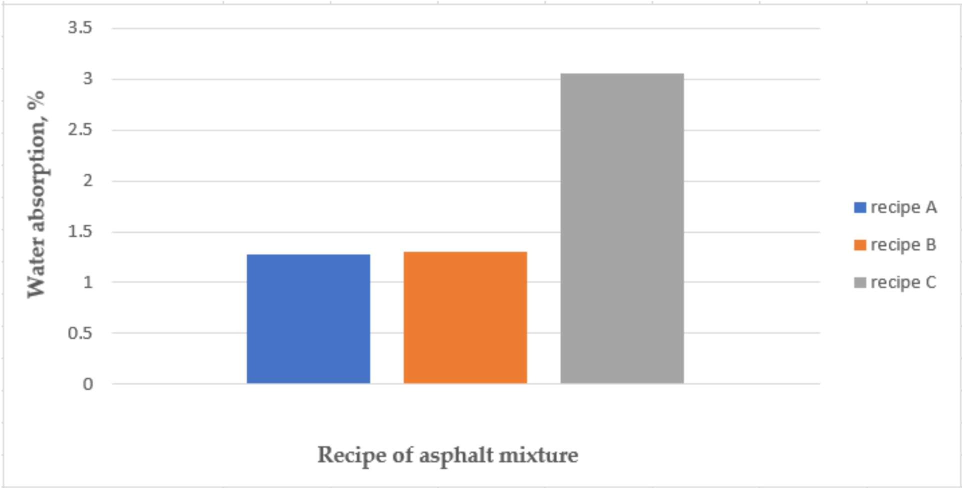

Figure 5. Water absorption versus recipe of asphalt mixture

Water absorption is 2% higher in the case of recipe B than recipe A and by 240% in the case of recipe C than recipe A.

The value of the stiffness modulus was determined using the indirect tension test (IT-CY), carried out in accordance with the requirements of EN 12697-26, Appendix C. This test includes measuring the vertical and horizontal displacement at the mid-height of the specimen and monitoring the applied force that generates the predicted displacement. The horizontal displacement of the sample was 5 ± 2 μm, the diameter of the samples tested was 101,6 mm. The duration of the increase in force shall be 124 ± 4 ms. After the application of the five sample conditioning pulses, five loading pulses of 124 ms duration shall be applied to the specimen, and for each loading pulse application, the variation of the applied load and the horizontal diametral deflection with time shall be measured and recorded, and the area factor of the load shall be determined, after which the specimen shall be removed from the apparatus, rotated 90° and similarly tested on the second diameter

Indirect tension test IT-CY on cylindrical samples was made according to European Standard SR EN 12697 - 26 C Annex, a temperature of 20^{o}C (conform SR EN 13108-20), resulting the stiffness modulus of the asphalt mixture. The results obtained are presented in Figure 6.

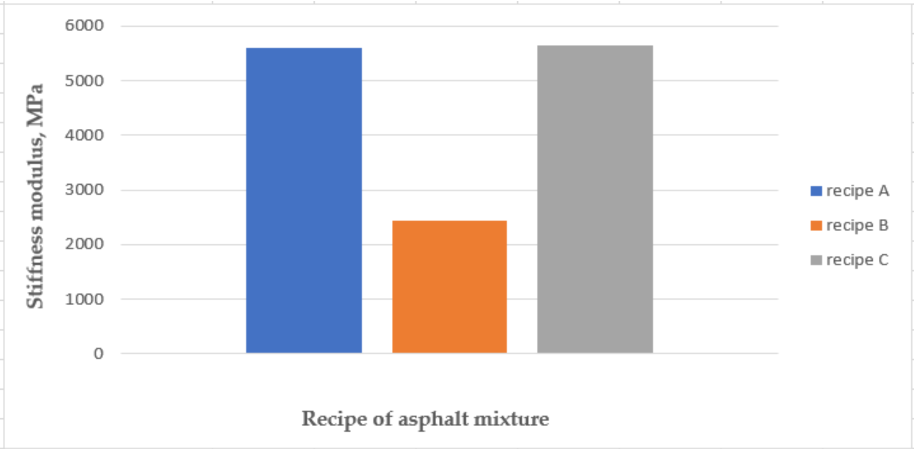

Figure 6. Stiffness modulus versus recipe of asphalt mixture

Stiffness IT – CY for 20°C temperature is 1% higher for recipe C than recipe A and 56% higher for recipe A than recipe B.

In order to have the resistance to fatigue, four point bending test 4PB – PR on prismatic samples was performed, according to European Standard SR EN 12697 – 24 D Annex, temperature of 20°C and frequency of 30Hz (conform SR EN 13108 – 20).

The prismatic beam is subjected to periodic four-point bending with free rotation and translation at all reaction and loading points. The bending is achieved by loading the two inner load points (inner flanges) in vertical direction perpendicular to the longitudinal axis of the beam. This loading configuration creates a constant moment, and hence a constant deflection, between two inner flanges. The applied load is sinusoidal. During the test, the load required to bend the specimen, the deflection and the phase shift between these two signals, is measured as a function of time.

The initial value of the calculated S_{mix} modulus is calculated from the measured values for force, displacement and phase shift after the 100 cycles. The fatigue test continues until the calculated Smix modulus has decreased to half of its initial value or until the sample breaks. The samples were conditioned for 4 hours at 20°C.

The results obtained are presented in Figure 7.

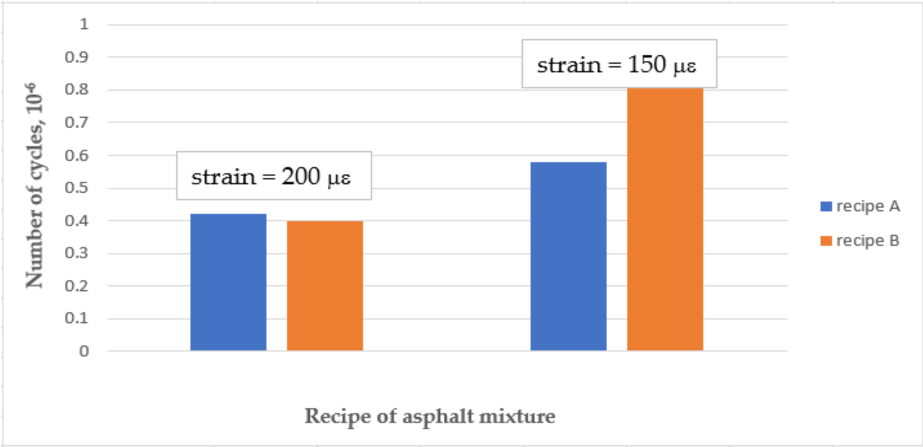

Figure 7. Resistance to fatigue versus recipe of asphalt mixture

The resistance to fatigue (number of cycles) is 5% higher for recipe A than recipe B for 200 με and 32% lower for 150 με.

Resistance to fuel was carried out according to European Standard SR EN 12697 – 43.

The cylindrical specimens were partially submerged in a fuel bath for 72 h. After removal from the bath, cleaning with water and drying for 24 h in a ventilated oven at 25 °C, the mass loss of the specimens was measured and the immersed surface area was checked.

The results obtained are presented in Figure 8.

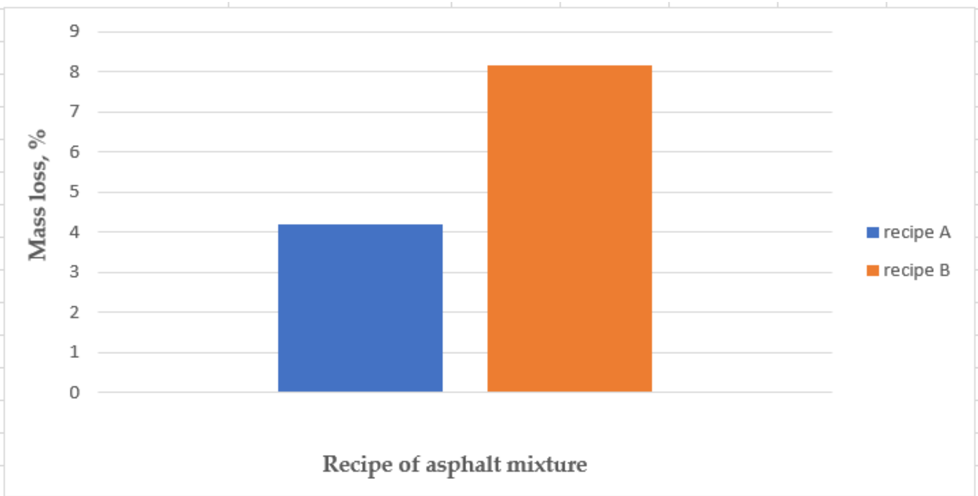

Figure 8. Mass loss versus recipe of asphalt mixture

Mass loss after 72 hours is about 94% higher for recipe B than for recipe A.

In order to determine the resistance to permanent deformation, cyclic compression test on cylindrical samples was carried out in laboratory, according to European Standard SR EN 12697 – 25, for triaxial compression at a temperature of 50°C, 300KPa axial load, confining pressure 1barr, 1s/1s frequency (pulse block).

The 100 mm diameter sample, maintained under high temperature conditions, is placed between two parallel flat metal disks. The test specimen is subjected to an axial cyclic pulsating pressure superimposed with the application of a lateral friction pressure. During the test, the change in specimen height is measured and the cumulative axial deformation (permanent deformation) is plotted as a function of the number of cycles. The specimens were placed in a temperature controlled enclosure and monitored until the test temperature of 50°C was reached. The conditioning period was 4 hours.

The results obtained are presented in Table 3 and Table 4.

Table 3. Resistance to permanent deformation for asphalt mixture, method 1, depending on recipe of asphalt mixture

Recipe of asphalt mixture	**Parameters of equation on stage II** $\varepsilon_n = A_1 + B_{1n}$		**Creep rate** $f_c = B_1$, **μm/m/n**	**Creep modulus** $E_n = \sigma/\varepsilon_n$, **KPa**	
	A1	B1		5000	10000
A	8978.5	0.0319	0.0319	328	322
B	8766.2	0.0308	0.0308	336	330
C	18399	0.033	0.033	162	160

Table 4. Resistance to permanent deformation for asphalt mixture, method 2, depending on recipe of asphalt mixture

Recipe of asphalt mixture	**Parameters of equation on stage II** $\log\varepsilon_n = \log A + \log B_n$		**Permanent deformation** ε_{1000} $\varepsilon_{1000, calc} = A1000^B$	**Permanent deformation** ε_{10000} $\varepsilon_{10000, calc} = A1000^B$
	A	B		
A	7375	0.025	8765	9285
B	7229	0.0246	8568	9067
C	16611.2	0.013	18172	18724

Tests results obtained on the final asphalt mixtures are presented in Table 5-9.

Table 5. Marshall results obtained

Results	Recipe of asphalt mixture	S, KN	F, mm	Q, KN/mm
Laboratory results	A	17.74	6.53	2.72
	B	14.37	5.85	2.46
	C	15.04	5.15	2.92
SR EN 13108-1	A	$MS_{min12.5}$	F_5	$Q_{min2.5}$
	B	$MS_{min12.5}$	F_5	Q_{min2}
	C	$MS_{min12.5}$	F_5	$Q_{min2.5}$

Table 6. Stiffness results

Results	Recipe of asphalt mixture	IT-CY, 20ºC, 124μs	4PB-PR, 20ºC, 8Hz
Laboratory results	A	5590	6777
	B	4429	6198
	C	5647	-
SR EN 13108-1	A	$S_{min5500}$, S_{maxNR}	$S_{min5500}$, S_{maxNR}
	B	$S_{min3600}$, S_{maxNR}	$S_{min5500}$, S_{maxNR}
	C	$S_{min5500}$, S_{maxNR}	-

Table 7. Resistance to permanent deformation in triaxial compression results

Results	Recipe of asphalt mixture	Max creep rate, μm/m/n
Laboratory results	A	0.0319
	B	0.0308
	C	0.0330
SR EN 13108-1	A	$f_{cmax0.2}$
	B	$f_{cmax0.2}$
	C	$f_{cmax0.2}$

Table 8. Resistance to fatigue results

Results	Recipe of asphalt mixture	Strain
Laboratory results	A	200
	B	200
SR EN 13108-1	A	$\varepsilon_{6\text{-min}190}$
	B	$\varepsilon_{6\text{-min}190}$

Table 9. Resistance to fuel

Results	Recipe of asphalt mixture	Mass loss after 72 h, %
Laboratory results	A	4.21
	B	8.17
SR EN 13108-1	A	<5
	B	>5

3. CONCLUSIONS

The use of bitumen with low penetration and high softening point (PMB 45/80 Fr) in the asphalt mixture conduct to both Marshall stability and flow values greater. The use of aggregates from Revărsarea in the asphalt mixture conduct to both Marshall stability and flow greater values than use of aggregates from Turcoaia.

Resistance to fuel is good in case of using PmB 45/80 Fr (regardless of type aggregates) and weak in case of using PmB 45/80-65.

A greater bulk density and value resistance to freezing and thawing, for aggregates, leading to a lower stiffness, same category for creep rate and higher Marshall characteristics.

A lower penetration and a higher softening point lead to greater stiffness regardless of the type of testing (IT-CY or 4PB).

For asphalt mixtures with special airport bitumen (A and C) the stiffness modulus is about 50% higher.

The resistance to fatigue (number of cycles) is 5% higher for for asphalt mixture with special bitumen for airports for 200 με and 32% lower for 150 με.

Permanent deformation is 105% less in case of recipe A than in case of recipe C and 2% higher in case of recipe B. The creep rate is 4% lower for recipe A than recipe C and 4% higher for recipe B.

Influence of additive in bitumen (PmB 45/80 Fr) lead to a good resistance to fuels.

These presented above results were obtained in laboratory depending on aggregates type and bitumen type, regarding asphalt mixture used in a pavement for low and medium traffic.

Finally, we recommend to study the asphalt mixture characteristics taking into account samples with 75 blows/side Marshall compaction when the traffic is heavy and very heavy.

The quality of the materials used in an asphalt asphalt mix plays an important role in the subsequent in-service behavior of the mix, so aggregates with high mechanical strengths, bitumens with low susceptibility to temperature variations and an optimal percentage of bitumen and filer should be used to make up the asphalt mixtures.

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