THE EFFECTS OF RUBBER PODWER ON THE PERFORMANCE OF PAVEMENT ASPHALT

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ABSTRACT

Romanian highway traffic grew substantially in the last decade, which combined with the severe climate conditions (low temperature winters and high temperature summer) led to necessity to produce pavements with asphalt mixtures with higher resistance at permanent deformations and cracking. Therefore, several new materials were tested to determine which ones are suitable for the specific climate and traffic in our country.
The paper presents the results which were obtained in the field and laboratory, on the asphalt mixtures prepared with rubber powder (itself, blend with semi-crystalline polyoctenamer or granulated with bitumen) which improves the pavement behavior and increase the lifetime of the road.
Product use has economicaly advantage and an minor impact on envinronment, because the rubber podwer is obtained from recycled tires.
The application technology of the product has the advantage to be introduced in two different ways: directly in the bitumen (wet procedure) or directly in the aggregates mix (dry procedure).
In laboratory the rubber powder was used in generally in the wet procedure, the modified bitumen being analyzed after SHRP methodology (RTFOT, PAV, DSR, and BBR).
In"situ" the rubber powder was used only in dry procedure, to applied asphalt mixture type SMA and AC on the national roads for the different geographical areas of country, respectively: mountain, hill and plain areas.
For the asphalt mixture, the resistance to rutting, stiffness, fatigue and dynamical creep was determined and also used for the evaluation of asphalt pavement behavior on the road.

Keywords: rubber powder, polyoctenamer, asphalt mixture, asphalt pavement

1.INTRODUCTION

In the last decade, in our country, given the specific climate conditions (high temperatures during summer and low temperatures during winter) and the increasing of the allowed road auto vehicle axle load (from 100KN to 150 KN), concerns were manifested regarding the use of road work materials and technologies that would ensure the proper conduct of operation (e.g. resistance to permanent deformation (ruts), low temperatures).
In this respect, as a result of the conducted studies and research, fiber stabilized asphalt and polymer modified bitumen have been favorited in road rehabilitation work, the SHRP bitumen performance class classification methodology has been adopted, and the bitumen is now being used according to specific climatic conditions.
As known, the use of polymer modified bitumen increases the strength to permanent deformations (ruts) [1-6], the strength to thermal and fatigue cracks [7], as well as the durability of the ashpalt pavement surface [2,8].
In Romania, the use of SBS (styrene butadiene styrene) and EGA (ethylene glycidyl acrylate) types of polymers has led to the improvement of the bitumen performance grade at high temperatures, which, in turn, led to a better rut resistance of asphalt. Depending on the type of the bitumen base, these polymers also improve the performance grade at low temperature [9].
The rubber powder can be then used to prepare asphalt;implementing this technology as an alternative to the thermoplastic elastomers used to modify bitumen was seen as being appropiate, considering that:

- Worldwide efforts to reduce CO2 emissions have intensified, in order to protect the environment;
- The technologies that use non-degradable waste in the process of asphalt fabrication, turning them into a useful product, are getting in line with the current trends of ecology and environmental protection;
- One source of road bitumen modification polymer is represented by used tires, from the recycling of which rubber powder can be obtained.

2. EXPERIMENTAL APROACH

While preparing the asphalt used in surface course (of AC and SMA types), different forms of rubber powder were used: simple granulated form (GP), rubber powder mixed with polyoctenamer (OP) and granulated with bitumen form (BP). Laboratory studies were conducted, as well as experimental sectors in different geografical/climatic areas of the country.

2.1 Simple granulated rubber powder(GP)

In the laboratory, rubber powder of 0-2mm and 0-4 mm granulation was used to create an asphalt of maximum aggregate size of 16 mm, in two versions:

- As a replacement for a part of natural sand and/or filler
- As an addition to the asphalt, in a quantity that would not influence asphalt features in a negative way
  Both versions required adding the powder to the heated aggregates (175-180 C), while the blending time was increased by 20-30 seconds and sample compactation took place at a temperature of 150 C.

The asphalt sets that were prepared were submitted to classical laboratory tests. The selected versions were those in which the rubber powder brought some improvement to the technical characteristics, such as:
-GP1 – 0-2mm powder, 1% addition to the asphalt
-GP2- 0-4mm powder, 1% of the mixture mass, replacing natural sand
-M- witness, without rubber powder.

The versions are as shown in table no.1, compared to the witness recipe.

Table 1: Properties of aspalt concrete with and without rubber powder

Properties	Asphalt Concrete BA16				Romanian requirements2002
	GP1	GP2	GP3	M	
Density, kg/m^3	2324	2342	2308	2365	min.2300
Water absorbtion ,%	2,0	0,8	0,7	0,4	2…5
Stability , kN	8,7	9,2	9,2	8,2	min.7
Flow, mm	3,5	4,4	4,1	4,3	1,5…4,5

1.1 Experimental area – surface course of asphalt concrete BA16 with added rubber powder

The experimental sector was carried out in the west part of the country, in autumn 2006, on the DN 68 national road, in a field area, using an addition of 1% powder mixture (0-2 mm and 0-4 mm) to the asphalt. The materials used to prepare the mixture, except the bitumen, were different from the ones used in the laboratory, but the grading curve was similar.

The results that were obtained on the asphalt taken from the layer and the ones obtained on the core taken a year after the execution are as shown in table no.2. After 4 years of use, the sector shows no degradation.

Table 2: Properties of asphalt concrete with GP on experimental area

Properties	Asphalt concrete BA16			Romanian requirements2002
	Witness sample	With GP, to layer	With GP, after 1 year in situ*	
Binder content, %	6,0	6,2	6,1	6,0...7,5
Compaction grade, %	-	-	100	min. .
Water absorbtion , % - core - Marshall cylinders	 - 4,0	 - 4.5	 1,3 -	2…5
Stability, kN	11.4	10,8		min.7
Flow, mm	3.9	3,5		1,5…4,5
Stiffness, MPa	8000	6200	-	-
Permanent deformation (triaxial compression) - deformation , µm/m	1053	4500	-	-
Fatigue - number of the cycles to cracking	350000	163000	-	-

* cores take n from the road

2.2 Rubber powder mixed with polyoctenamer (OP)

The blend is made up of 95.5% rubber powder with a particle diameter of less than 1.4 mm and 4.5% semi-crystalline polyoctenamer. There is a chemical reaction between the double bonds present in the polyoctenamer, the sulfur in the rubber powder and the bitumen, that facilitates an uniform composition of the blend [10].
The blend is used in preparing the asphalt, either by modifying the bitumen, either by adding directly into the heated aggregates, during the asphalt preparation process. In both cases, the added powder/polyoctenamer mixture content can represent between 5% to 20% of the bitumen's mass [10].

2.2.1. Laboratory tests

In the laboratory, the 50/70 penetration bitumen was modified using 10% powder/rubber blend, the same percent of blend also being used for preparing BA16 aspalt concretet. Witness samples have been used for comparison purposes.
Bitumen modification was conducted via the wet procedure, in which the powder/polyoctenamer blend was added to the bitumen (that had been heated up to 180° C), in small amounts and being homogenized by shaking. For a proper processing of the modified binder obtained, it was intended that the final viscosity be between 200 and 3000 mPa.s, the reaction time being determined by measuring the viscosity (it was considered that the reaction was complete when the viscosity remained constant for an hour). Stirring the blend for two hours was considered enough for the reaction to take place. During modification, the bitumen tank was filled up to about two thirds of the maximum filling height, to avoid flooding bitumen generated by the rubber powder's tendency to inflate [11].
In the case of ashpalt preparation, the dry procedure was used: the powder/polyoctenamer blend was added to the aggregate (that had been heated up to 170° C), and then mixed for 90 seconds, after which the bitumen was added, and the mixing continued for another 90 seconds. After that, the material was left to condition for an hour, at 160° C, to allow the completion of the reaction [11].
Penetration, softening point and Fraass breaking point tests, as well as DSR and BBR tests, were carried out on the bitumen samples, in conformity with the SHRP methodology [12].
The asphalt samples were subjected mainly to the following tests:

- stiffness (15° C), according to SR EN 12697-26 / annex C;
- triaxial cyclical compression (strain and creep rate at 50°C, 1800 impulses/BA16 – 3600 impulses/SMA16, 300 Kpa), according to SR EN 12697 – 25, method B;
- fatigue (strain at 15°C, 10000 impulses, 250 Kpa), according to SR EN 12697 - 26 / annex E;
- wheel tracking (proportional depth of the ruth and creep rate to 60°C, 10000 cycles, 700 KN), according to SR EN 12697 – 22, small device, B method in air; according to the romanian technique norm 523 (60°C, 45 min., 520 KN) of 2008

The results of the tests carried out on the modified bitumen are as shown in table no. 3, and the ones carried out on asphalt are as shown in table no. 4.

Table 3 – Properties of 50/70 bimen unmodified and modified with rubber podwer/polioctenamer

Properties	Bitumen	
	unmodified	modified with 10% blend OP
Softening point ^{0}C	48	56,7
Penetration, 1/10 mm	57,2	39,5
Fraass breaking point, ^{0}C	-12,6	Did not crack
DSR, original, 64^{0}C		
G*/sinδ, Pa	1584	2513
G*, Pa	1580	2491
Δ, grade	85,8	72,5
BBR, at -18^{0}C		
Stiffness, S, MPa	246,8	196,3
Slope, m	0,380	0,360

Table 4 – Properties of asphalt concrete BA16 with and without OP addition

Properties	BA16	BA16 with 10% blend OP
Asphalt temperature , ^{0}C	150	170
Density, kg/m^3	2388	2330
Water absorbtion, %	0,5	1,2
Stability, kN	10	12,3
Flow, mm	4,6	3,3
Stiffness, mm	6250	6600
Triaxial compression - deformation , µm/m	5200…6700	5200…6900
Fatigue -deformation, mm	1,46	0,37
Wheel Tracking* - rut depth , mm - WT slope, mm/hour	 5 4,3	 3,4 0,7

* - tests made in accordance with romanian norm. 573

2.2.2 Surface course of BA16 and SMA16- asphalt with added rubber powder/polyoctenamer

During 2008-2010, the powder/polyoctenamer blend was used for preparing BA16 and SMA16 asphalt for the surface course (dry procedure), which were used in the works of an experimental sector on the DN10 national road, in a mountain area, and in the works done on derouting road of Sibiu, in a hill area. The asphalt's behavior was watched both during wintertime, as during heavy traffic during summertime. The results are shown in table no. 5.

Table 5 – Properties of asphalt with rubber podwer/polioctenamer blend (OP) in situ

Asphalt type Layer place	Properties	Value	SR 174/1-2009
BA16 with OP DN10, 2008	Stiffness, MPa	6700	-
	Triaxial compression - deformation, µm/m - creep rate, µm/m/ciclu	 5480 0,18	-
	Fatigue, 10000 cycles - deformation , mm	 0,37	-
	Wheel Tracking - ruth depth, mm - WT slope, mm/ora	 3,4 0,3	* < 7 < 3
BA16 Core with OP DN10, 2009	Water absorbtion, %	2,8	2...5
	Compaction grade, %	97,8,,,99,6	min. 96
	Wheel Tracking - proportional ruth depth, % - WT slope, mm/10^3 cicluri	 7,5 0,11	 max.9 max.1
*SMA16 with OP Centura ocolitoare Sibiu, 2010	Stiffness, MPA	7730	min.4500
	Triaxial compression - deformation, µm/m - creep rate, µm/m/ciclu	 7750 0,20	 max.30000 max.3
	Fatigue, 3600 cicluri - deformation , mm	 0,530	 max.1
	Wheel Tracking - proportional ruth depth, % - WT slope, mm/10^3 cycles	 5,7 0,1	 max 7 max.0,6

* requirements of SR 174/1-2002, good in 2008

2.3 Granulated rubber powder- bitumen (BP)

The rubber powder/bitumen granulated blend is made up of 45-50% bitumen, 40% rubber powder and 10-15% filling material, grain size being about 10 mm [13].

The BP blend is used by directly adding it into the asphalt industrial plant, immediately after downloading the aggregates; there is a special procedure for the laboratory procedures (as seen in 2.3.1).

2.3.1 Laboratory tests

The bitumen-granulated rubber powder (BP) was used in the lab for the modification of the 50/70 penetration bitumen and for preparing an AC16-type asphalt (of 6.2% 50/70 penetration bitument content); the witness sample was used for comparison purposes. The results of the tests carried out on the modified bitumen are as shown in table no.2, and the ones carried out on the asphalt are as shown in table no.3.

In this case, the BP granulate was mixed with 50/70 penetration road bitumen, heated at 190°C-200°C, in a paddle mixer, and then homogenized by shaking, at a speed of 200 rot/min, for 15-20 minutes. The BP granulate content was 12% of the bitumen mass.

The resulting modified bitumen is not stable in storage, and must be used within 15 minutes of preparation. For this reason, for every asphalt, a new modified bitumen blend was prepared, according to the following preparation technology [14]:

- heating the aggregates up to 160°C in an oven
- putting the heated aggregates into the mixing bowl and mixing it with the homogenization filler, for about 10-15 sec
- adding the BP-granulate-modified bitumen to the aggregates and mixing for about 5 min, until the blend is homogenous
- the temperature at the end of the compaction must be of 145°C

Table 6 – Properties of 50/70 and 70/100 bitumen unmodified and modified with BP.

Properties	**Bitumen 50/70**		**Bitumen 70/100**	
	Unmodified	Modified with 12% BP	Unmodified	Modified with 12% BP
Softening point, ^{0}C	49,5	56,5	46,3	50,5
Penetration, 1/10mm	57	38	79	60
Fraass breaking point, ^{0}C	-15,2	-13,4	-13	-14
Adhesion to aggregates, %	74	83	84	84
DSR, original				
G*/sinδ at 64^{0}C, Pa	1680	3945	1116	2520
DSR, after RTFOT				
G*/sinδ at 64^{0}C, Pa	4013	8220	2020	3775
DSR, after PAV				
G*sinδ at 22^{0}C, Pa	4607	3235	5286	3395

Table 7 – Properties of asphalt concrete BA16 with an without BP granulated

Properties	**BA16**	**BA16 with 12% BP granulated**
Density, kg/m^3	2548	2534
Stability, KN	8,6	10,4
Flow, mm	5,9	5,0
Stiffness, MPA	4900	8700
Triaxial compression - deformation, µm/m	62160	23390
Fatigue - deformation , mm	1,45	0,30

2.3.2. Using the BP granulate on the field

On the field, the bitumen/powder granulate was used in creating an experimental sector of SMA asphalt, on the DN3 national road , derouting road of A2 highway and in the works done on the A2 highway. The BP granulate asphalt contained 5.8% bitumen, 12% (of the bitumen's mass) BP granulate and a granulometric curve that corresponds to the requierements of the SR 174/2009 romanian technical standard. The projected recipe was verified in the laboratory and then applied on the field.
Commisioning the work was done as follows:

- dosing the heated aggregates (160°C-180°C)
- putting the BP granulate directly into the asphalt industrial plant
- dry mixing for about 10 seconds
- adding the bitumen (max. 190°C) and mixing for at least 20 seconds, in order to homogenize the blend

The results that were obtained are as shown in the following diagrams:

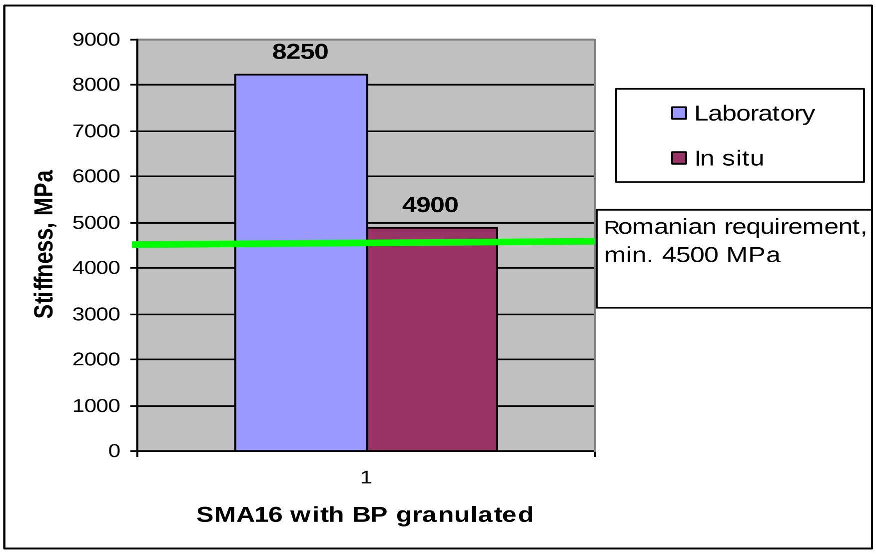

Figure 1: Stiffness of SMA16 with BP granulated

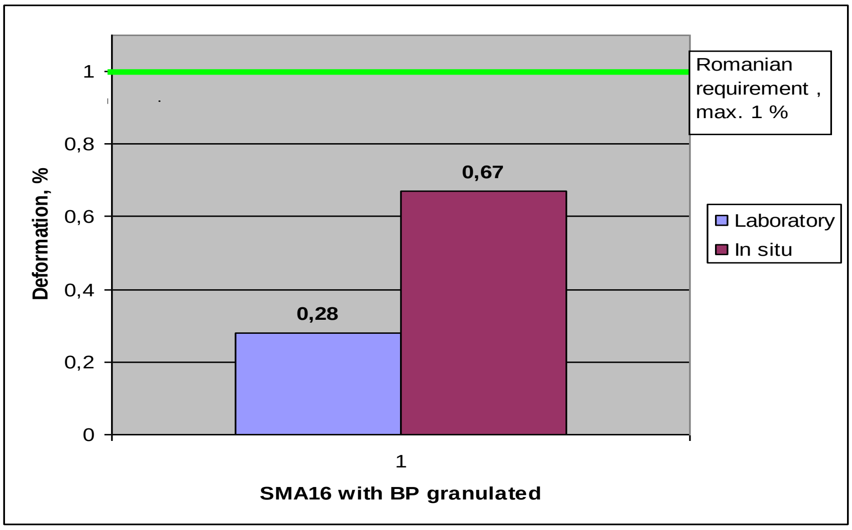

Figure 2: Resistance to fatigue of SMA16 with BP granulated

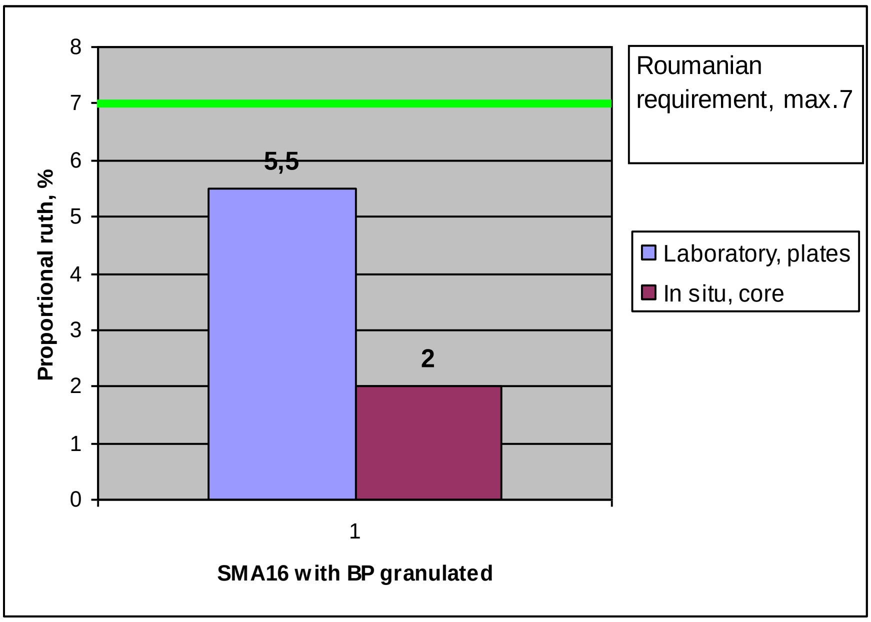

Figure 3: Wheel tracking of SMA16 with BP granulated

3. RESULTS AND DISCUSSION

3.1 Simple rubber powder

For the same dosage of rubber powder in the asphalt, in the laboratory, the influence on the final product depends on the type of powder that is being used: the finer type (0-2 mm) leads to a decrease of the flow index, while the medium type leads to an increase in stability.

On site, the use of 1% blend of 0-2mm and 0-4mm led to the obtention of stabilities and flow indexes that were comparable to those of the witness-blend; despite this, the characteristics of the dynamic tests (stiffness, triaxial compression and resistance to fatigue) were weaker.

3.2 Rubber powder mixed with polyoctenamer

Modifying the 50/70 penetration bitumen in the laboratory, with a blend of powder/polyoctenamer, for a given temperature:

- the complex shear module value increases and the lag angle decreases, which points to an increase in elasticity and, hence, an increase of the resistance to permanent deformation
- the stifness value decreases, which shows a better resistance to cracking at low temperatures.

Using the rubber powder/polyoctenamer blend in preparing BA16 asphalt concrete in the laboratory improves ruth resistance (the depth and forming speed of the ruts decrease) and fatigue resistance; it also slightly stiffens the blend and increases stability.

Powder/polyoctenamer blended asphalt used on site as surface course met the technical requirements imposed by the SR 174/1-2009 Romanian technical standard, showing a good resistance to wheel tracking and dynamic creep. Its behavior in time was appropriate: after 3 years, respectively 1 year, in service, there was no degradation.

3.3 Bitumen-granulated rubber powder

Using the bitumen-granulated rubber powder (BP) to change the 50/70 and the 70/100 penetration bitumen, for a given temperature, leads to:

- an increased $G^*/\sin\delta$ ratio, thus leading to increased rut resistance
- a decrease in the G*s inδ product, thus leading to increased fatigue cracking resistance.

After the RTFOT and PAV aging, the bitumen modified with BP granulate shows Fraass breaking point values similar to the ones of the non-aged bitumen (-13.2°C/-12°C for the bitumen and -13°C/-11.2°C for the 70/100 bitumen).
Carrying out the tests requires special attention and a greater number of samples to be tested, as it is influenced by the homogeneity of the blend.
The BBR test was not eloquent in this case, because the asphalt specimens kept bending (without cracking or breaking) when subjected to the test temperatures (-12°C and -18°C) and the machine was not recording the values for the rigidity module or the m slope.
In the case of the BA16 asphalt concrete in the laboratory, the BP granulated increased the stiffness, improving stability, fatigue resistance and dynamic creep.
In the field, the recipe designed to create a wear layer of SMA asphalt in the laboratory was not completely reproduced (lower stiffnesss, greater fatigue cracks), even if the bulk densities were similar. This is probably due to the greater volume of voids that was obtained on the asphalt used on-site (6,2% against 4% in laboratory). The values of the obtained characteristics were, nevertheless, according to the conditions imposed by the Romanian technical standards. Wheel tracking resistance is good, as the rut depth values are low. Differences between results from plates and results from cores taken from the road are due to the way of compaction, which, in the laboratory, was conducted using the roll on sliding boards procedure.

4. CONCLUSIONS

Simple rubber powder can be used in preparing asphalt, with a maximum dosage of 2% of the blend's mass. At a higher dosage, the obtained asphalt does not show characteristics according to the technical standards.
Simple rubber powder can be used either as a 0-4 typer natural sand replacement (a maximum of 30% of the total natural sand), either as an addition to the asphalt's composition (maximum 1%).

Rubber powder mixed with polyoctenamer, used in a 10% content in the preparation of asphalt, reduces the tendency of rut apparition, improving the permanent cracking resistance (rut depth and ruth forming speed decrease); it also improves the asphalt's fatigue resistance, which leads to a decrease in the cracking caused by this phenomenon.

Using the rubber powder/bitumen granulate in making asphalt, as to represent 12% of the asphalt blend, improves stability and fatigue behavior, increases rut resistance and can also increase adesivity of binders with low affinity to aggregates

For all three forms of rubber powder, it is recommended that the dry procedure be used: adding the powder over the heated aggregates (160-180 °C) in the mixer station, and then following the procedure that we described above, to each separate product.

Using rubber powder present the advantages of environmental compatibility, maintenance cost reduction and an asphalt production that doesn't require the asphalt plant to be modified.

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