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Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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Road and Rail Infrastructure V

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INCREASE OF ASPHALT RECYCLING BY USING PYROLYSIS PRODUCTS OF WASTE TIRES

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Abstract

Bitumen, which is the most important component of asphalt and has the biggest impact on its behaviour, is ageing during the use of asphalt layers. Ageing of bitumen is most frequent cause for degradation of asphalt layers. Finally this leads to the removal of asphalt layers. But asphalt granulate obtained from the removed asphalt layer can be added to freshly produced asphalt mixtures. Using special additives, i.e. rejuvenators, bitumen can regain its basic properties, and in this way we can increase the proportion of asphalt granulate added to the asphalt mixture. We developed alternative rejuvenator with the process of pyrolysis of waste tires [1]. First, we tested the efficiency of the various pyrolytic products that were produced by varying the time and temperature of the pyrolysis. Various concentrations (3 %, 5 %, 10 % and 20 %) of the most suitable pyrolytic product were mixed into bitumen. We examined its effect on the viscoelastic properties of fresh and laboratory aged bitumen [2]. With standard mechanical tests, rheological investigations and rheological modelling, we have proven that with the addition of the alternative rejuvenator to aged bitumen some basic properties of bitumen are regained. We determined the most appropriate bitumen content that should be added to a mixture of fresh asphalt and reclaimed asphalt. Finally standard tests of asphalt mixtures showed that the addition of rejuvenator improves the properties of asphalt mixtures containing the reclaimed asphalt, and the rate of recycling can be increased. Reuse of reclaimed asphalt means reducing waste material and so preserving the environment.

Keywords: rejuvenator, pyrolysis, reclaimed asphalt, bitumen ageing

1 Introduction

It was interest at the beginning of the study, to evaluate the possibility to use a pyrolytic product from waste tires as an adequate substitution for the bitumen binder [3]. Optionally we were trying to use the pyrolytic product only as an additive. Finally, we found out that our pyrolytic product can be used as an additive i.e. alternative rejuvenator [4]. With this work we have solved two important problems:

a) product of waste tires was used instead of expensive raw materials in the asphalt mix,
b) The amount of reclaimed asphalt (RA) in new asphalt mixture increased.

We produce more and more waste every year in Europe. Total waste generation in 2012 was 2.52 billion tonnes in the European Union (28 countries), out of which the plastic waste was 18.6 million tonnes [5]. In 2010, 3.3 million tonnes of waste tires were collected in Europe (EU 27 + NO + CH). Most of the waste tires are reused as a material or for energy recovery. Nevertheless, 157 thousand tonnes are landfilled [6]. Waste legislation in European Union dictates

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the following hierarchy regarding the waste management: re-use, recycling, recovery, and as the last option: disposal [7]. This is the reason why waste was used as a raw material for the new product in our study.
In the past removed asphalt layer was also treated as waste. The most common solution to recycle asphalt is to add up to 20 % RA into freshly produced asphalt mixtures. More sophisticated solution is the usage of rejuvenators. The added rejuvenators revert the basic properties of aged bitumen. In this way the recycling rate of asphalt granulate can be increased.

2 Bitumen and pyrolytic products mixtures

2.1 Materials

All pyrolytic products that we tested had been obtained by the pyrolysis of waste car tires. The products were prepared by the pyrolysis in liquid mass in a batch reactor, where the pyrolysis took place up to 350 °C. Products were prepared by repeating the procedure with temperature, mixing intensity and time variations; several products were obtained.
Bitumen of the penetration grade 50/70 (B 50/70), from the producer MOL, Hungary, was used as a matrix of the blends. Bitumen was mixed with the pyrolytic products. All the blends were produced in the laboratory by adding a controlled quantity of the pyrolytic products to the bitumen. The blends of bitumen and pyrolytic products were produced by mixing two of the components in ratios of 1:1. Each of the blended samples weighed 100 g, i.e. 50 g of the pyrolytic products used and 50 g of bitumen. The blending process consisted of heating both components to the mixing temperature for 60 minutes and pouring the required masses into a small container. The two components were then manually stirred together for approximately 60 s in order to produce a uniformly distributed binder blend. The blends were then poured into sample containers and stored at 5 °C prior to testing. In order to test the affinity between binder and aggregate, we used the aggregate fraction 8/11 from Bleiburg, Austria. We assumed that the chemical composition of the aggregate was silicate rock.

2.2 Methods

In order to characterize the pyrolytic products, some standard testing methods were used for bituminous mixtures, as defined in the European standards. The penetration, the softening point, the ductility and the Fraass breaking point were determined in order to make the comparison between the bitumen, the pyrolytic products, and their blends. Viscosity was measured with a dynamic shear rheometer (DSR). With temperature ramp measurement we determined temperatures where the viscosity of the measured material is 0.17 Pas and 0.26 Pas. The viscosity of bitumen around 0.17 Pas is demanded when asphalt is mixed in asphalt mixer and around 0.26 Pas when asphalt is built in.

2.3 Results

In Table 1 are results of the test on the blends of bitumen and 14 different pyrolytic products in ratios of 1:1. In the last raw are results of the test on pure bitumen. We searched for a blend of bitumen and pyrolytic products with similar viscosity as was found for pure bitumen. Elongation at ductility test should be as long as possible. The Fraass breaking point should be as low as a possible and softening point should decrease. From table 1 it can be seen that sample 14 was the closest to our expectations, so we chose pyrolytic product number 14 for further tests.

Table 1 Results of test on the blends of bitumen and pyrolytic products in ratios of 1:1

Bitumen + pyrolytic products no.	R&B softening point [°C]	Fraass breaking point [°C]	Ductility [mm]	Temperature where viscosity is (n=0,17 Pas)	Temperature where viscosity is (n=0,26 Pas)
1	43.3	-12.8	902.44	152.1	125.8
2	46.4	-8.4	534.14	146.0	123.3
3	47.1	-18.3	334.53	143.6	121.9
4	46.9	-11.4	1500.01	146.6	123.3
5	46.6	-10.4	1492.35	152.1	128.0
6	44.8	-18.3	759.86	142.2	119.2
7	45.7	-14.1	1500.01	140.1	118.2
8	52.3	-5.6	1500.01	150.7	129.1
9	38.1	-23.6*	1500.00	158.6	129.3
10	37.2	-21.9	1500.01	135.3	113.8
11	-	-24.0*	-	140.3	105.2
12	40.2	-21.3*	1325.67	176.8	143.5
13	45.4	-14.4	1500.01	169.9	140.8
14	42.6	-18.8	1122.3	139.6	117.2
Pure bitumen	**50.5**	**-10.8**	**1500.01**	**141.2**	**121.9**

** no break at the end of the test*

Then we mixed bitumen and pyrolytic product number 14 (PP) in various ratios. In Table 2 it can be seen that 3 % (m/m) of PP has practically no effect on softening point and penetration, but higher concentrations PP makes bitumen softer. We were also curious if mixing law for bitumen is also valid for a mixture of bitumen and PP sample. Mixing law for softening point and penetration is determined in standard SIST EN 13108-1 by equations (1) and (2).

$$T_{R\&B,m} = \frac{b_0}{100} T_{R\&B,0} + \frac{b_{PP}}{100} T_{R\&B,PP} \quad (1)$$

$$\log pen_m = \frac{b_0}{100} \log pen_0 + \frac{b_{PP}}{100} \log pen_{PP} \quad (2)$$

From the Table 2 it can be seen that mixing law for bitumen is valid also for PP at low concentrations.

Table 2 Results of test on the blends of bitumen and PP sample number 14 in different in ratios

% of PP	Measured R&B softening point [°C]	Calculated R&B softening point [°C]	Measured penetration [mm]	Calculated penetration [mm]
3	50.2	50.1	55	55
5	50.3	49.9	59	57
10	49	49.2	60	61
20	47.3	47.9	75	71
Pure bitumen	50.5		55	
Pure PP	37.5		233	

Rejuvenator is used for rejuvenation of aged bitumen. To simulate real conditions, we aged bitumen in the laboratory and mixed it with PP. For ageing bitumen, we used standardised RTFOT (EN 12607-1:2007) and PAV (EN 14769:2012) methods. In Table 3, it can be seen that with the addition of PP aged bitumen becomes softer. It can be also seen that mixing law for bitumen is valid for penetration, but the softening point is even a bit lower than it is expected from mixing law. This is also according to our expectation. The expected effect of rejuvenator is to make aged bitumen softer than when adding only fresh bitumen.

Table 3 Results of test on the blends of aged bitumen and PP sample number 14 in different in ratios

% of PP	Measured R&B softening point [°C]	Calculated R&B softening point [°C]	Measured penetration [mm]	Calculated penetration [mm]
3	69	69.4	22	23
5	67.7	68.8	22	24
10	65.6	67.1	26	27
20	61.6	63.8	34	34
Aged bitumen	70.4		21	
Pure PP	37.5		233	

To evaluate adhesion between PP and stone aggregate we used "rolling bottle test" according to standard EN 12697-11. We used pure PP, a mixture of PP and bitumen in ratio 1:1 and for reference, this test was performed also with pure bitumen. From the Table 4 it can be seen that there is no significant difference in results for all tested samples.

Table 4 Adhesion between stone aggregate and bitumen and PP

Bitumen + PP	Time [h]				
Sample	**0**	**6**	**24**	**48**	**72**
B50/70	100	95	80	55	40
B50/70+PP	100	95	80	50	30
PP	100	95	90	55	45

3 Asphalt mixtures

3.1 Materials

First, reclaimed asphalt (RA) is obtained from asphalt plant Laže. From the same asphalt plant we obtained limestone filler and limestone fractions 0/2 mm, 2/4 mm and 4/8 mm. The RA was prepared in same fractions. The same bitumen (B 50/70), as in previous tests of bitumen and PP, was used in asphalt mixtures. From those constituents we prepared 7 different asphalt concrete AC 8 mixtures. In all mixtures content of binder was 5 % (m/m) including PP content. Fresh material was mixed with 0, 20, 40 and 60 mass percent of RA.
Basic data about laboratory produced asphalt mixtures are presented in Table 5. It can be seen that only relatively small amount of PP was added to the asphalt mixture.

Table 5 Laboratory prepared asphalt mixtures

Asphalt mixture	Binder content	PP content	Density	Maximal density	Void content
	[% (m/m)]	[% (m/m)]	[kg/m³]	[kg/m³]	[% (V/V)]
% RA	5	0	2398	2478	3.2
% RA	5	0	2403	2490	3.5
% RA + PP	5	0.17	2407	2492	3.4
% RA	5	0	2407	2494	3.5
% RA + PP	5	0.34	2394	2492	3.9
% RA	5	0	2425	2502	3.1
% RA + PP	5	0.50	2417	2501	3.4

3.2 Methods and results of asphalt tests

First the water sensitivity test, according to EN 12697-12 was performed. From Fig. 1 it can be seen that Indirect tensile strength ratio (ITSR) was increasing with increased RA content. There is the insignificant difference between mixture containing PP and mixtures without PP (PP is designated as poml. in Figure 1). Then the wheel tracking test, according to EN 12697-22 was performed. From Table 6 it can be seen that proportional rut depths (PRD) are similar for all asphalt mixtures.

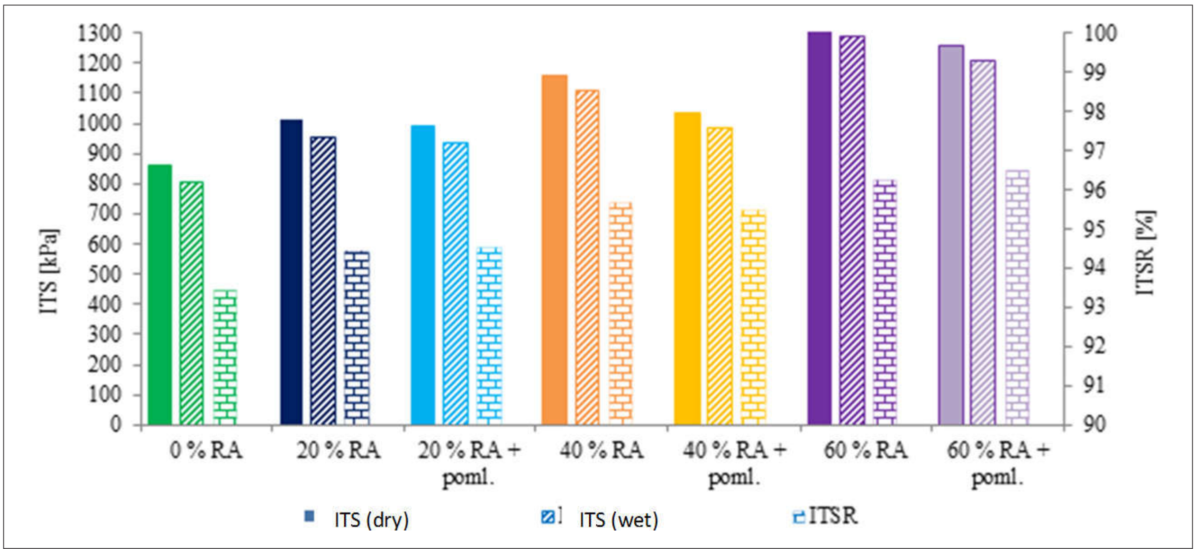

Figure 1 Results of water sensitivity test

Table 6 Results of wheel tracking test

Asphalt mixture	d_{5000} [mm]	d_{10000} [mm]	WTS	PRD [%]
% RA	2,17	2,57	0,08	5,1
% RA	1,86	2,17	0,062	4,3
% RA + PP	2,25	2,53	0,056	5,1
% RA	2,28	2,64	0,072	5,3
% RA + PP	2,12	2,48	0,072	5,0
% RA	2,01	2,3	0,058	4,6
% RA + PP	1,85	2,18	0,066	4,4

Finally, low-temperature Thermal Stress Restrained Specimen Test (TSRST) according to EN 12697-46 was performed. From Table 7 and Fig. 2 it can be seen from both main test results Failure temperature $T_{failure}$ and Failure stress $\sigma_{cry,\ failure}$ that resistance to low temperature is restored when PP is added to asphalt mixture containing 60 % RA. Results show even a bit better resistance than for reference asphalt mixture.

Table 7 Results of low-temperature Thermal Stress Restrained Specimen Test

Asphalt mixture	Failure temperature $T_{failure}$ (°C)	Failure stress $\sigma_{cry,\ failure}$ (MPa)
% RA	-27,73	4,34
% RA	-24,44	4,51
% RA + PP	-28,35	4,78

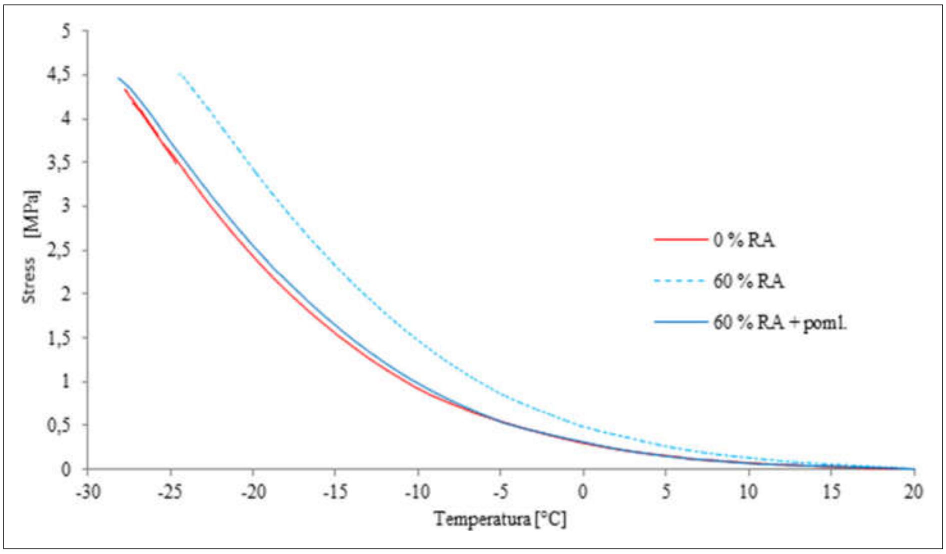

Figure 2 Results of low-temperature Thermal Stress Restrained Specimen Test

4 Conclusions

In this study, we developed alternative rejuvenator with the pyrolyse of waste tires. We had to determinate:

- parameters of pyrolysis,
- the most suitable pyrolytic product, which was in the further steps used as rejuvenation,
- mechanical and rheological properties of the chosen rejuvenator,
- the optimal proportion of the rejuvenator in bitumen, which improved the properties of aged bitumen from reclaimed asphalt,
- the content of reclaimed asphalt (RA) in the fresh asphalt mixture.

With standard asphalt tests we verified that addition of pyrolytic product improved the mechanical properties of asphalt mixtures containing reclaimed asphalt. The content of reclaimed asphalt can be increased up to 60 %. Reuse of reclaimed asphalt means reducing waste material, while maintaining the environment.

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