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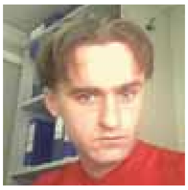

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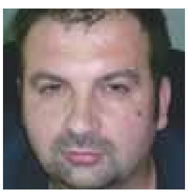

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Professional paper

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Use of recycled asphalt in the bituminous base course

Tests aimed at determining adequacy of use of recycled asphalt in the bituminous base course BNS-32s, for cases of very heavy traffic load, are presented in the paper. The proportion of recycled asphalt used in these asphalt mixes amounted to 20, 25 and 30 percent. Physicomechanical properties of asphalt mixes were tested according the HRN EN-12697. The results obtained show that the use of recycled asphalt in the production of bituminous base course BNS-32s is possible, and that it is an adequate solution from the standpoint of economy and environmental compliance.

Key words:
pavement structure, recycled asphalt, bituminous base course, BNS-32s

Stručni rad

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Primjena recikliranog asfalta u bitumeniziranom nosivom sloju

U radu su opisana ispitivanja primjene recikliranog asfalta u bitumeniziranom nosivom asfaltnom sloju BNS–32s za vrlo teško prometno opterećenje. Udio recikliranog asfalta u ispitivanim asfaltnim mješavinama razmatran je u iznosu 20, 25 i 30%. Ispitivanja fizikalno-mehaničkih svojstava asfaltnih mješavina provedena su prema normi HRN EN-12697. Dobiveni rezultati pokazuju da je primjena recikliranog asfalta u proizvodnji bitumeniziranoga nosivog asfaltnog sloja BNS-32s moguća te predstavlja ekonomski i ekološki opravdano rješenje.

Ključne riječi:
kolnička konstrukcija, reciklirani asfalt, bitumenizirani nosivi asfaltni sloj, BNS-32s

Fachbericht

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Anwendung von rezykliertem Asphalt in der bituminösen Tragschichte

In der Arbeit werden Prüfungen der Anwendung von rezykliertem Asphalt in der bituminösen Asphalttragschichte BNS–32s bei sehr schwerer Verkehrsbelastung aufgezeigt. Der Anteil an rezykliertem Asphalt in den geprüften Asphaltmischungen wurde in dem Betrag von 20 %, 25 % und 30 % gemessen. Die Prüfung der physikalischen mechanischen Eigenschaften erfolgten nach der Norm HRN EN-12697. Die erhaltenen Resultate zeigen, dass die Anwendung von rezykliertem Asphalt in der Herstellung der bituminösen Asphalttragschichte BNS-32s möglich ist und eine wirtschaftlich und ökologisch gerechtfertigte Lösung darstellt.

Schlüsselwörter:
Fahrbahnkonstruktion, rezyklierter Asphalt, bituminöse Tragschichte, BNS-32s

1. Intrudaction

In the Republic of Croatia, an intensive construction of new motorway sections was initiated in 1990s and so there are currently more than 1500 km of motorways on the national level. The country has about 30,000 km of roads and motorways, out of which 7,500 km are national roads, while county and local roads account for 21,000 km [1, 2]. Presently, the need to build new roads and motorways is less and less felt, and a high emphasis is now placed on the maintenance of existing roadways. An increasing traffic load to which roads are exposed on the daily basis, and their inevitable ageing, is causing considerable damage to pavement structures, either in form of cracking or rutting. Until recently, the maintenance of asphalt pavement structures implied construction of new levelling layers made of bituminized material, and an asphalt-concrete wearing course. It was generally believed that the quantities of materials for the construction and maintenance of roads are practically unlimited. However, the operation costs, environmental protection requirements, and the cost of natural stone transport to asphalt plants, have greatly modified former way of thinking so that now new, more efficient and cost-effective procedures, aimed at replacing natural materials, are being considered. One of them is the asphalt pavement recycling procedure known as RAP (Reclaimed Asphalt Pavement) that has been in use in many countries for three decades now. It is estimated that more than 500 millions of tons of RAP material are produced worldwide each year [3]. Denmark, Germany and the Netherlands use RAP material for the production of new asphalt courses in more than 50 percent of cases. A similar situation has been registered in Japan and Great Britain, while in our country the use of RAP material is quite negligible [4].

Asphalt pavement recycling enables reuse of material that has already been placed into pavement structure.

Various economic and legal considerations, and recent developments in technology and equipment, have had a positive effect on the implementation of recycling technologies. Limited quantities of natural aggregates, and high price of crude oil, are economic reasons that have spurred development of new recycling technologies and techniques. Current legislation encourages recycling and reuse of materials, reduced generation of waste, and lower CO_2 emissions, and sets high penalties and fines for non-compliance. According to its origin, the recycled asphalt can be endogenous – when it originates from the same pavement that is recycled "in situ", or exogenous - when it is transported from an another location to the recycling site. Asphalt pavement recycling methods can be divided into two basic categories:

- method applied in stationary plants, or "in plant" method,
- method applied in situ, or "in place" method.
- In addition, these two recycling methods can be further subdivided, depending on asphalt placing temperature, into two additional categories:
- hot recycling method
- cold recycling method

Advantages and disadvantages of basic recycling categories are presented in Table 1.

2. Laboratory testing

Physicomechanical properties of recycled asphalt mix samples, crushed stone material fractions of sedimentary origin, stone flour of category KB-I, and road bitumen 50/70 (according to EN 12591:1999), were tested in the laboratory of the company Osijek-Koteks d.d [7]. The recycled asphalt was obtained by mechanical milling of the existing bituminous wearing course BNHS 16, and the milling produce was then added as a replacement of a part of stone aggregate and paving bitumen for production of the new asphalt mix for the bituminous base course BNS-32s. The proportions of recycled asphalt in asphalt mixes tested amounted to 20, 25 and 30 percent. The following materials were used in the preparation of laboratory asphalt mixes:

- stone flour (Veličanka Quarry),
- stone chippings 0/4, 4/8, 8/16, 16/31.5 (Veličanka Quarry),
- paving bitumen 50/70 (Sisak Refinery),
- recycled asphalt (Osijek – West Bypass).

Table 1. Advantages and disadvantages of basic recycling categories, [6]

Recycling method	Advantages	Disadvantages
In place recycling	- high quality of recycled mix - grading can be checked - mix is highly homogeneous - mix can be improved - old bitumen is used - can be reused in a new asphalt wearing course - high flexibility of use	- potentially more expensive - high power consumption - high material transport cost - RAP material storage - environmental pollution/emissions
In plant recycling	- full use of RAP material - highly cost-effective and efficient - road can rapidly be put to traffic - favourable for small and big projects - low cost of transport - recycling can be made on one traffic lane if needed	- a new surface layer is needed - problem with heterogeneity of existing asphalt - long recycling activities are not favourable for smaller and/or rural roads - simple recycling equipment is favourable for small volume and rural roads only

2.1. Stone aggregate grading

Stone chipping fractions 0/4, 4/8, 8/16, 16/31.5, originating from the Veličanka Quarry, with the grading as shown in Table 2, were used in the preparation of trial asphalt mixes. Physicomechanical properties of bituminous asphalt mixes (whose composition is shown in Table 3) were also tested. The following physicomechanical properties were tested:

- Density of asphalt sample according to HRN EN 12697-5 [10],
- Density of asphalt mix according to HRN EN 12697-6 [11],
- Voids content according to HRN EN 12697-8 [12],
- Voids in stone mix according to HRN EN 12697-8 [12],
- Percent voids filled with asphalt according to HRN EN 12697-8 [12].

The stone mix grading was determined according to HRN EN 12697-2 [9], and the soluble part of the building bitumen according to HRN EN 12697-1 [8].

2.2. Preparation of asphalt mixes

After the recycled asphalt was delivered to the laboratory, the material was dried at the temperature of 25°C for 24 hours. The recycled asphalt extraction (separation of bitumen from stone aggregate) was conducted on three samples so as to determine the paving bitumen content and

Table 2. Grading of stone chippings (Veličanka Quarry)

Fractions / Sieve [mm]	Rock flour		0/4		4/8		8/16		16/31,5	
	mass %	Σ	mass %	Σ	mass %	Σ	mass %	Σ	mass %	Σ
0,063	72,6	72,6	6,0	6,0	1,1	1,1	0,7	0,7	0,4	0,4
0,09	10,0	82,6	0,2	6,1	0,0	1,1	0,0	0,7	0,0	0,4
0,125	7,70	90,3	2,5	8,6	0,0	1,1	0,0	0,7	0,0	0,4
0,25	7,50	97,8	9,2	15,3	0,3	1,4	0,1	0,7	0,1	0,4
0,50	1,50	99,3	18,8	24,9	0,3	1,6	0,2	0,9	0,0	0,5
0,71	0,70	100,0	7,1	32,0	0,2	1,9	-0,1	0,9	0,0	0,5
1,00			8,9	40,9	0,4	2,3	0,1	0,9	0,0	0,5
2,00			27,6	68,5	1,8	4,1	0,3	1,2	0,1	0,5
4,00			28,8	97,3	13,1	17,2	0,6	1,8	0,0	0,6
8,00			2,6	99,9	79,2	96,4	7,5	9,3	0,1	0,7
11,20			0,1	100,0	3,3	99,7	44,8	54,1	0,0	0,7
16,00					0,3	100,0	45,0	99,1	6,7	7,4
22,40							0,9	100,0	45,7	53,1
31,50									46,9	100,0
Aggregate fineness modulus HRN U.E4.014.			5,98							
Silty particles HRN B.B8.036. (mass %)			6,11		0,01		0,66		0,36	
Proportions of undersize particles HRN U.E4.014. (mass %)					17,18		9,33		7,41	
Proportions of oversize particles HRN U.E4.014. (mass %)			2,73		3,59		0,94			

Table 3. Designed asphalt mix composition (proportions of individual constituents)

Material / Mixes	Rock flour [%]	Paving bitumen [%]	Recycled asphalt [%]	Stone chippings [%]
Mix I	2,0	2,38	30,0	68,0
Mix II	2,5	2,61	25,0	72,5
Mix III	3,0	2,85	20,0	77,0

Table 4. Grading of recycled asphalt samples

Stone mix grading according to HRN EN 12697-2															BITUMEN
SIEVE [mm]	0,063	0,09	0,125	0,25	0,5	0,71	1,0	2,0	4,0	8,0	11,2	16,0	22,4	31,5	HRN EN 12697-1
AV. VALUE	11,1	12,2	13,6	17,4	23,3	27,4	32,3	47,2	66,6	89,6	97,3	100,0			4,75
Min. content	9,6	10,5	11,7	14,8	19,5	22,8	26,9	39,7	58,4	85,2	96,9	100,0			4,36
Max. content	12,1	13,3	14,7	18,8	25,2	29,9	35,2	51,1	71,2	92,0	97,7	100,0			4,97
Stand. dev.	1,3	1,5	1,7	2,2	3,3	4,0	4,7	6,5	7,1	3,8	0,4	0,0	0,0	0,0	0,34

an average grading. The results obtained are shown in Table 4 and Figure 1.

An average grading of recycled asphalt samples is shown in Figure 1. According to its composition, the recycled asphalt mix was defined as the bituminous wearing course with maximum aggregate grain size of 16 mm.

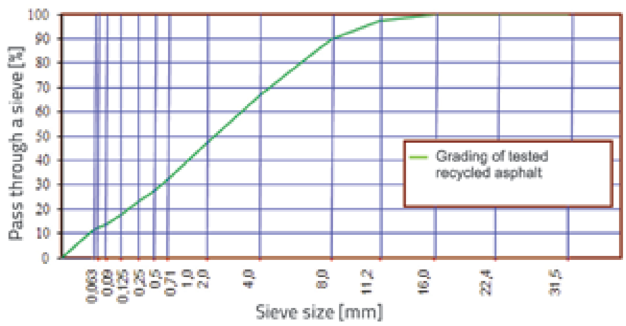

Figure 1. Average grading of asphalt samples

2.3. Preparation of mix designs and laboratory samples

The mix design was defined for the bituminous asphalt mix to be used in a bituminous base course. The stone material mix is characterized by the maximum nominal grain size of 31.5 mm, and by narrow grain size distribution boundaries [8].

Laboratory asphalt mixes contain 30 %, 25 % and/or 20 % of recycled asphalt. Designed and realized asphalt mix samples are presented in Figures 2a – 4b. Deviations between the designed and realized asphalt mixes with thirty percent of recycled asphalt are presented in Table 5.

2.3.1. Asphalt mixes with 30% recycled asphalt for BNS-32s

The design grading curve for the asphalt mix with 30 % of recycled asphalt is shown in Figure 2a. The grading curve was designed in such a way to make the greatest possible savings in paving bitumen.

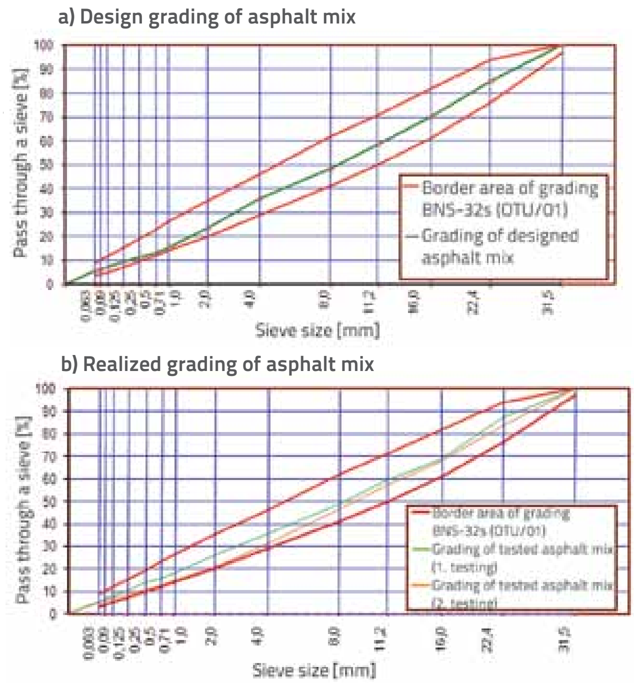

Figure 2. Grading of two asphalt mixes with 30% of recycled asphalt

2.3.2. Asphalt mixes with 25% recycled asphalt for BNS-32s

The design grading curve for the asphalt mix with 25 % of recycled asphalt is shown in Figure 3a. The grading curve deviation for asphalt mixes with 25% of recycled asphalt occurs in the range from 0.71 and 8.00 mm, and from 11.20 to 22.40 mm, where the grading curves points to somewhat coarser asphalt mix composition when compared to design values, cf. Figure 3b.

2.3.3. Asphalt mixes with 20% recycled asphalt for BNS-32s

Realized grading values for asphalt mix with 20 % of recycled asphalt are very close to design values, cf. Figures 4a and 4b. It can therefore be concluded that it is easier to achieve design values with smaller recycled asphalt content in the mix.

Table 5. Deviation between the design and realized asphalt mix with 30% of recycled asphalt

Sieve size [mm]	Design values [%]	First testing		Second testing	
		Test results [%]	Difference compared to design value	Test results [%]	Difference compared to design valueg
0,063	5,39	5,50	0,11	5,00	-0,39
0,09	5,95	6,30	0,35	5,60	-0,35
0,125	6,71	7,80	1,09	6,70	-0,01
0,25	8,59	10,40	1,81	8,60	0,01
0,50	11,18	13,90	2,72	11,00	-0,18
0,71	13,05	15,80	2,75	12,40	-0,65
1,00	15,35	18,10	2,75	14,60	-0,75
2,00	23,06	25,90	2,84	20,80	-2,26
4,00	33,91	35,20	1,29	30,80	-3,11
8,00	48,4	48,80	0,40	46,30	-2,10
11,20	58,61	59,60	0,99	57,40	-1,21
16,00	69,29	68,90	-0,39	67,90	-1,39
22,40	84,51	87,10	2,59	83,30	-1,21
31,50	100,00	100,00	0,00	100,00	0,00
bitumen	3,80	3,90	0,10	3,86	0,06

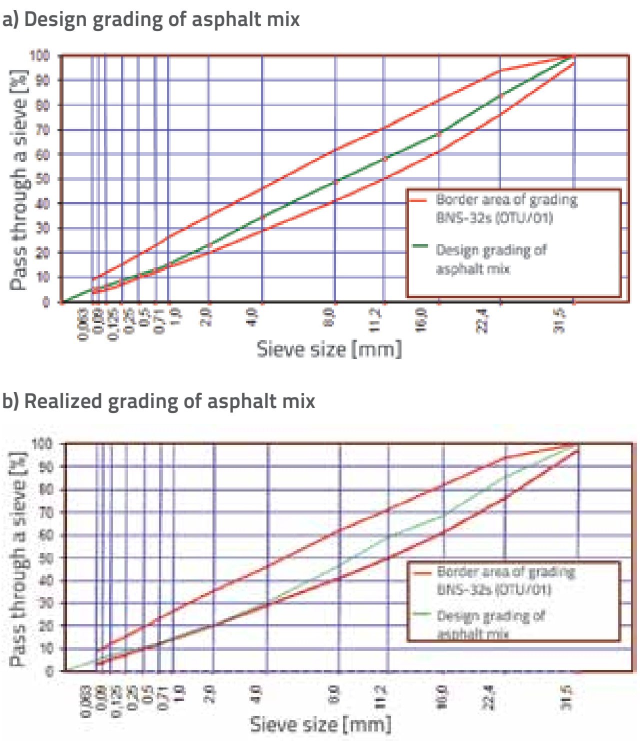

Figure 3. Grading of asphalt mix with 25 % of recycled asphalt

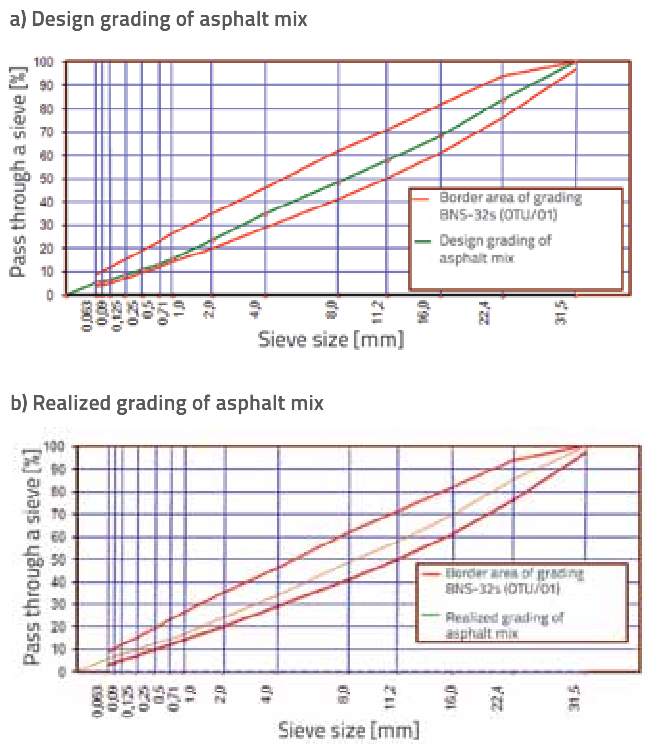

Figure 4. Grading of asphalt mix with 20 % of recycled asphalt

2.4. Physicomechanical properties of laboratory samples

Asphalt mixes prepared in laboratory comply with limits specified in OTU (General Technical Requirements), Volume III (Table 5-04-8) for motorways and roads with an extremely high traffic load. Physicomechanical properties of asphalt mixes are given in Table 6.

2.5. Economic considerations

After laboratory analysis of recycled asphalt samples obtained by milling the bituminous wearing course BNHS 16 it was established that the building bitumen accounts for 4.75% of the mix. The target building bitumen proportion amounts to 3.8% for the design asphalt mix for preparation of the bituminous base course BNS-32s. A detailed presentation of savings in asphalt mix sample components, for various proportions of recycled asphalt in the mix, is given in Table 7.

3. Conclusion

Results obtained by laboratory testing of samples, with the use of recycled asphalt mix for realization of the bituminous base course BNS-32s, for very high traffic load, and using

Table 6. Physicomechanical properties of asphalt samples for BNS-32s

Physicomechanical properties for BNS	Asphalt mix with 30% of recycled asphalt	Asphalt mix with 25% of recycled asphalt	Asphalt mix with 20% of recycled asphalt	Requiremetn according to OTU Volume III (Table 5-04-8)
Density of asphalt sample [kg/m³] (HRN EN 12697-5)	2.509,00	2.509,00	2.495,00	-
Density of asphalt mix [kg/m³] (HRN EN 12697-6)	2.675,00	2.685,00	2.661,00	-
Voids content [% (v/v)] (HRN EN 12697-8)	6,19	6,55	6,24	5-8
% voids in stone mix [% (v/v)] (HRN EN 12697-8)	15,74	15,51	15,85	-
% voids filled with bitumen [% (v/v)] (HRN EN 12697-8)	60,68	57,73	60,65	51-67

Table 7. Individual proportions of asphalt mix components for BNS-32s

Mix components \ Asphalt mixes	Standard asphalt mix	Mix I (30 % of recycled asphalt)		Mix II (25 % of recycled asphalt)		Mix III (20 % of recycled asphalt)	
	Component proportion [%]	Component proportion [%]	Savings with respect to standard mix [%]	Component proportion [%]	Savings with respect to standard mix [%]	Component proportion [%]	Savings with respect to standard mix [%]
Rock flour	6	2,00	66,67	2,50	58,33	3,00	50,00
Building bitumen	3,9	2,38	37,50	2,61	31,25	2,85	25,00
Reciklirani asfalt	-	30,00	-	25,00	-	20,00	-
Stone aggregate 0/4 mm	25	10,00	30 %	13,50	25 %	17,00	20 %
Stone aggregate 4/8 mm	15	8,00		9,00		9,00	
Stone aggregate 8/16 mm	20	17,00		16,00		17,00	
Stone aggregate 16/31,5 mm	34	33,00		34,00		34,00	

recycled asphalt proportions of 30 %, 25 %, and 20 %, are presented in the paper. The following conclusions were made based on the above-mentioned testing:

- Variability of recycled asphalt mix complicates the process of controlling individual proportions of stone chippings, rock flour, and difference in the paving bitumen requirement.
- After extraction of bitumen from recycled asphalt, it was established that bitumen deviation may attain up to 13.99 %.
- Narrow grading limits of the rock mix for BNS-32s complicate considerably the design of the asphalt mixes with higher proportions of recycled asphalt.
- The grading curve deviation for asphalt mixes with 25 % of recycled asphalt occurs in the range from 0.71 and 8.00 mm, and from 11.20 to 22.40 mm, where the grading curves points to somewhat coarser asphalt mix composition when compared to design values.
- Required (design) values for asphalt mixes are easier obtained if the recycled asphalt content is reduced.
- All laboratory asphalt mix samples comply with limits specified in OTU (General Technical Requirements), Volume III (Table 5-04-8) for motorways and roads with an extremely high traffic load.
- Savings in the quantity of paving bitumen, stone chippings, and rock flour greatly depend on the type of recycled asphalt. As the asphalt wearing course with an average bitumen content of 4.75 % was used in this laboratory testing, the savings in bitumen ranged from 25 % to 37.5 % depending on the proportion of recycled asphalt in the design asphalt mix.

Results obtained by testing asphalt mixes containing recycled asphalt for realization of the bituminous base course BNS-32s for very high traffic load conditions, show that this technical solution is fully justified, both from the economic and environmental standpoints. Future studies should focus on the analysis of possibilities for producing these mixes in asphalt plants, and on preparation of test sections so as to test applicability of recycled asphalts in other types of asphalt mixes.

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