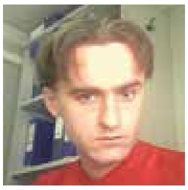
UDK 625.85.004.67:69.003.1

Građevinar 5/2013

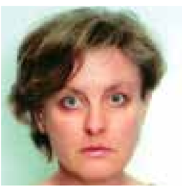
Primljen / Received: 19.2.2012.
Ispravljen / Corrected: 21.3.2013.
Prihvaćen / Accepted: 13.5.2013.
Dostupno online / Available online: 10.6.2013.

Cold recycling of asphalt pavements using foamed bitumen and cement

Authors:



Ivica Androjić, MCE
Osijek-Koteks d.d.
ivica.androjic@osijek-koteks.hr



Gordana Kaluđer, MCE
Kombel d.o.o.
gordana.kaludjer@kombel.hr

Professional paper

Ivica Androjić, Gordana Kaluđer

Cold recycling of asphalt pavements using foamed bitumen and cement

The technological procedure of in-situ cold recycling of asphalt pavement, using the foamed bitumen and cement during pavement structure rehabilitation works on the Knin – Biskupija section of the D1 National Road, is presented in the paper. The technological procedure presented in the paper enables high percentage of material recovery from the existing pavement structure, and thus the need to use natural material is reduced. The pavement structure rehabilitated using the studied procedure has an appropriate bearing capacity, monolithic properties, and resistance to freezing.

Key words:
asphalt pavement, cold recycling, pavement rehabilitation, foamed bitumen

Stručni rad

Ivica Androjić, Gordana Kaluđer

Hladno recikliranje asfaltnog kolnika primjenom upjenjenog bitumena i cementa

U radu je prikazan tehnološki postupak hladnog recikliranja asfaltnog kolnika na licu mjesta primjenom upjenjenog bitumena i cementa na obnovi kolničke konstrukcije državne ceste D1, na dionici Knin – Biskupija. Prikazanim tehnološkim postupkom ostvaruje se visoki postotak iskoristivosti materijala iz postojeće kolničke konstrukcije čime je smanjena potreba za prirodnim materijalima. Obnovljena kolnička konstrukcija s analiziranim postupkom ima potrebnu nosivost, monolitnost te otpornost na smrzavanje.

Ključne riječi:
asfaltni kolnik, hladno recikliranje, obnova kolnika, upjenjeni bitumen

Fachbericht

Ivica Androjić, Gordana Kaluđer

Kaltrecycling von Asphaltfahrbahnen durch die Anwendung von Schaumbitumen und Zement

In der vorliegenden Arbeit ist das technologische Verfahren des Kaltrecyclings vor Ort durch die Anwendung von Schaumbitumen und Zement in der Instandsetzung der Landesstraße D1 auf dem Abschnitt Knin - Biskupija dargestellt. Mit dem beschriebenen Verfahren wird eine hohe Verwendungsrate des bestehenden Materials erzielt, und somit der Bedarf natürlicher Rohstoffe reduziert. Die durch das beschriebene Vorgehen erneuerte Fahrbahnkonstruktion besitzt die erforderliche Tragfähigkeit, monolithische Struktur und Frostbeständigkeit.

Schlüsselwörter:
Asphaltfahrbahnen, Kaltrecycling, Fahrbahnerneuerung, Schaumbitumen

1. Introduction

Depending on available technology and equipment, recycling can be made using either cold or hot process, on construction site or in appropriate plants. Cold recycling is a technological procedure by which asphalt pavement layers are recycled without heating, and the mix improved with additives is then reused as pavement base course. Bitumen emulsions and foamed bitumen are used as additives. If the recycled mix properties have to be modified, then modifiers such as cement, lime and/or fly ash [1] are added so that an optimum moisture of the mix can be achieved. In addition, depending on the design solution, asphalt layers are also used to recycle bottom base courses of pavement structures.

In the Republic of Croatia, the cold in-place recycling technology based on foamed bitumen has so far been used during rehabilitation of national and county-level roads, and one of the roads rehabilitated using this technology is the national road DC 55 at the Vinkovci – Županja section, 17.80 km in length, which was rehabilitated in two phases in the course of 2008. The first phase concerned rehabilitation of the Gradište – Privlaka section from mid May to August, while the second phase of works lasted from October to November and, in that period, the pavement structure was rehabilitated on the Privlaka – Vinkovci section. The same pavement rehabilitation procedure was also used at the Labin – Štrmec section on the national road D 66/2, 1.8 km in length, and rehabilitation work was completed within five working days, from 21 to 27 April 2010. The county road 5077 Kanfanar – Žminj was upgraded at the stretch 2.547 km in length from 2 February to 15 June, while the rehabilitation of the national road D1 Pađene – Stara Straža, 5.879 km in section length, lasted 17 working days only, from 5 to 28 June 2011. The common denominator for all these rehabilitated sections is the relatively short time between the start of rehabilitation and opening to traffic of rehabilitated sections. The rehabilitation of the mentioned sections was conducted using the technological procedure developed by Wirtgen company [2, 3] because this procedures is still not covered by technical regulations currently in force in the Republic of Croatia.

2. Cold in-place recycling using foamed bitumen

The cold in-place recycling (CIR) is conducted by grinding existing asphalt layers down to 250 mm in depth, and mixing the obtained material with the crushed aggregate, cement or bitumen. The milled material is stabilized with the foamed bitumen [4]. The cold recycled asphalt can be used on both lower rank pavements and motorway pavements, but must meet appropriate resistance and stability requirements. In order to meet such requirements, the produced mass must be homogeneous so that a good adhesion between the crushed stone aggregate and bitumen can be obtained. The recycled aggregate must be properly graded so as to enable a uniform distribution of grains in the base course. Coarser grains of the recycled asphalt aggregate must not contain an excessive bitumen coating, so as to ensure proper adhesion between bitumen and stone grains, and to avoid emulsion fracturing in such zones [4].

The foamed bitumen is manufactured by adding small quantity of water to hot bitumen, i.w. 2 to 3 percent of water to the total quantity of bitumen. Road construction bitumens that are normally used in the production of hot asphalt mixes can also be used in the manufacture of foamed bitumen. However, bitumen types BIT 50/70 and BIT 70/100 are most often used for this purpose. When water is added to hot bitumen, it evaporates at a very fast rate, which causes expansive foaming of bitumen in the saturated water vapour. The volume of bitumen increases by 15 to 20 times with respect to its initial volume, which results in a significant reduction of viscosity. In this form, bitumen is very suitable for mixing with cold aggregate. Foaming properties are influenced by bitumen temperature (approximately 180°C), pressure at which bitumen is applied (approximately 500 kPa), and quantity of water that is added to bitumen. The structure of the material obtained in this way is very good as it contains no more than 10 percent of voids after compaction. In order to avoid possible deficiencies with respect to retained strength, 0.5 to 2.0 percent of cement or lime is added, in addition to bitumen.

Foamed bitumen quality parameters are:

- by increasing the quantity of water the relationship between the maximum foamed bitumen volume and its initial volume before foaming also increases (by 15 to 20 times),
- by increasing the quantity of water the time needed to reduce the maximum foamed bitumen volume by 50 % is reduced (10 to 15 seconds),
- spraying technology applied,
- as a rule, the quality of foamed bitumen increases with an increase in the relationship between the volume and maximum volume reduction time.

3. Pavement rehabilitation on the Knin – Biskupija section of the D1 national road

3.1 Preliminary investigations

The Knin – Biskupija section, from KM 1+817 to KM 7+655, 5.838 km in total length, forming part of the D1 national road, was rehabilitated in the period from 23 October to 13 December 2011, i.e. within 18 working days. The client was Hrvatske ceste d.o.o. (Croatian Road Ltd.), the main contractor was Osijek – Koteks d.d., the subcontractor for cold recycling works was Primorje d.d., Ajdovščina, and the quality control activities were conducted by TPA d.o.o. from Dugopolje. The road is situated near the town of Knin in the Republic of Croatia.

Preliminary activities started by visual inspection of pavement structure. During this inspection, it was established that the pavement is affected by rutting and block cracking (cf. Figure

4). Three trial excavations were made at KM 1+980 L, KM 4+242 S, and KM 5+660 D [5] in order to determine the composition, depth, and resistance to freezing of the existing pavement structure, and to create a mix design for rehabilitation of the pavement structure. These trial excavations revealed that an average depth of the existing asphalt is 13.5 cm, and that the underlying subbase made of loose stone material 0/32 mm in diameter is more than 18.0 cm in thickness. The freezing resistance of pavement structure was checked by comparing the pavement structure thickness with the freezing depth. It was established that the pavement structure does not have the required thickness of 45 (42) cm [6]. At the same time, the suitability of the existing pavement structure material, and of the 0/4 mm crushed limestone material to be added to the milled asphalt mix, was tested. The crushed stone material originating from the neighbouring Zemunik quarry was stockpiled at the construction site in quantities that were considered sufficient for an undisturbed realization of work (Figure 1).

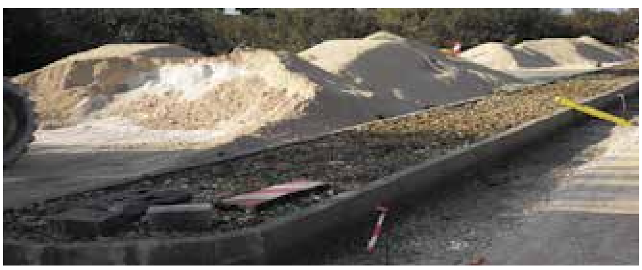


Figure 1. 0/4 mm crushed stone material stockpiled on the construction site

3.2. Initial and confirmed job-mix formulas

The preliminary job-mix formula for cold recycling based on foamed bitumen and cement was prepared in the Vrtojba asphalt laboratory using material from the existing pavement structure (asphalt surfacing and crushed stone mix), additional 0/4 mm crushed stone material, paving bitumen, cement, and water. The initial job-mix formula was prepared as specified in the Wirtgen Cold Recycling Manual [2, 3].

The composition of stone grains for recycled course was determined in accordance with HRN EN 933-1 – Determination of particle size distribution – Sieving method (EN 933-1:1997/A1:2005) [7]. Limit grading curves recommended by Wirtgen and Akroyd [2, 3] were applied for the selection of stone material mixes. The cement adopted in the job-mix formula is the mixed Portlad cement CEM II/A-M (S-V) 42.5 N.

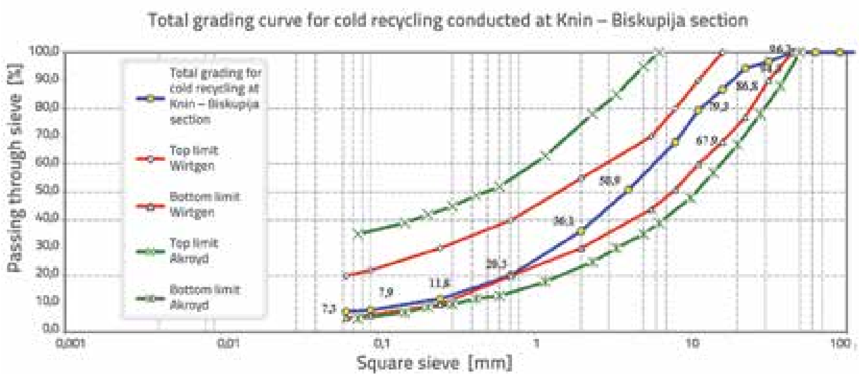


Figure 2. Total grain size distribution for cold recycling [9]

3.2.1. Mix grading

The mix grading was determined in accordance with the corresponding Croatian standard [8] taking into account recommendations given in [2, 3], as shown in Figure 2 [9].

Figure 2 shows the total grading of the mix containing the recycled asphalt obtained by milling, stone mix from the existing pavement structure (max. grain size: 45 mm), additional 0/4 mm stone fraction, and cement. The grading of the laboratory mix is 0/31.5 mm, with 3.3 % of grains greater than 31.5 mm.

3.2.2. Dry bulk density and optimum moisture of mix according to Proctor

The mix was tested according to the test method for laboratory reference density and water content – Proctor compaction (HRN EN 13286-2) [10], and it was established that an optimum water content is w_{opt} = 5,8 %, while the maximum dry bulk density of the sample is $r_{d,max}$ = 2173 kg/m^3. The testing was conducted on the total of four samples of the mix consisting of the existing milled asphalt, milled stone mix from base course, and 0/4 mm crushed stone material. The Proctor compaction test was conducted using the cylinder 12 cm in height, 15 cm in diameter, 2.005544 dm^3 in volume, and 4.215 kg in weight, and the hammer weighing 4.54 kg was released from the height of 45.7 cm in the series of 5 x 56 blows.

3.2.3. Optimum content of paving bitumen in recycled mix (ITS)

The paving bitumen BIT 70/100 released at the pressure of 12.0 bars at the rate of 105.0 g/s was selected for the initial job-mix formula. The water from the municipal water supply system was added at the pressure of 5.0 bars, and the air was introduced at the pressure of 4.0 bars. The following foaming requirements were applied: paving bitumen temperature: 170°C, water content: 2.8 %, expansion time: 13 s, and time needed to achieve maximum volume: 12 s. Requirements were set for the minimum indirect tensile strength of wet

Table 1. Determination of foamed bitumen properties [9]

Water content [%]	Water flow rate [l/h]	1. measurement		2. measurement		3. measurement		Average	
		Expansion ratio	t ½ [s]	Expansion ratio	t ½ [s]	Expansion ratio	t ½ [s]	Expansion ratio	t ½ [s]
1,3	5	4	18	4	16	6	17	5	17
1,9	7	6	15	6	15	6	15	6	15
2,4	9	10	13	12	11	13	12	12	12
2,8	11	12	12	13	12	13	12	13	12
3,4	13	13	8	12	12	11	8	12	10
4,0	15	16	7	16	7	15	6	16	7
4,6	17,5	18	5	18	5	18	5	18	5

Expansion ratio is the relationship between the maximum foamed bitumen volume and initial bitumen volume prior to the start of the foaming procedure.
t ½ (half-life time), is the time in which the maximum foamed bitumen volume reduces by 50 %, i.e. the time in which the expansion reduces to one half of its value

sample (min. 100 kPa) and dry sample (200 kPa), and also for the indirect tensile strength ratio of wet and dry samples (min. 50 %). The recycled mix contained 57.8 % of milled asphalt, 19.3 % of milled stone mix, 21.4 % of additional 0/4 mm stone material, and 1.5 % of cement. An optimum content of additional bitumen (2.5 %) was determined in laboratory based on the above mentioned criteria.

3.2.4. Determination of foaming properties of bitumen

The paving bitumen BIT 70/100, heated to the constant temperature of 170°C, injected under pressure of 12.0 bars at the rate of 105.0 g/s, as defined for the initial job-mix formula, was used in laboratory to test foaming properties of bitumen. The water from the public water supply system was added at various percentages in relation to the quantity of added bitumen, but under the same pressure of 5.0 bars. The air was injected under pressure of 4.0 bars. The total injection time was 4.76 s. Three measurements in total were made, and the corresponding results are presented in Table 1.

3.2.5. Initial job-mix formula for recycled mix

The initial job-mix formula for the recycled mix was prepared on the basis of: laboratory testing of pavement samples taken before rehabilitation work and 0/4 mm crushed stone material samples, determination of bulk density and optimum moisture content of recycled mix, and determination of foaming properties of the selected paving bitumen. The proportion of all mix components expressed in percentages and quantities (kg/m³) of recycled mix was determined in the initial job-mix formula. The initial job-mix formula defined indirect tensile strengths of dry and wet samples to be achieved during the cold in-place recycling procedure. The confirmed job-mix formula is presented in Table 2, while Table 3 shows tensile strength values for recycled mix during realization of the cold recycling with foamed bitumen, and also proportions of cement, water and additional paving bitumen in the total mix.

Table 2. Confirmed job-mix formula for the recycled mix [9]

Existing milled asphalt	57,8 %; 13,5 cm
Existing crushed stone mix	19,3 %; 4,5 cm
0/4 mm stone material (added)	21,4 %; 5,0 cm
Cement CEM II/A-M (S-V) 42,5 N	1,5 %
paving bitumen 70/100 (added)	2,5 %

Table 3. Realized compressive strength values and additive proportions

Indirect tensile strength of dry sample, ITSs	553 kPa
Indirect tensile strength of wet sample, ITSm	429 kPa
ITSm/ITSs ratio	78 %
Recycled mix	2173 kg/m³
Cement	32,6 kg/m³ (7,5 kg/m²)
Additional bitumen	54,3 kg/m³ (12,5 kg/m²)
Water	126,0 kg/m³ (29,0 kg/m²)

4. Selection of machines for cold recycling

Appropriate machines and vehicles for cold recycling using foamed bitumen and cement were selected. The recycling train consisted of the recycler, cement spreader, water truck, bitumen truck, roller, and grader. A part of the recycling train is shown in Figure 3.

Figure 3. Recycling train on construction site

The recycler used on the project, Wirtgen WR 2500, has the following features:
- required granularity and homogeneity of the mix is obtained by one pass only,
- milling drum is 2.44 m in width, and the drum turning rate can be changed,
- the recycling down to the depth of 50 cm is possible in a single pass; the recycling depth depends on the depth of asphalt layers,
- all systems used for injecting water and foamed bitumen are controlled by micro-processor and are automatically adjusted depending on the operating speed of the recycler.
- The cement spreader used, Streumaster RW 12000, has the following features:
- capacity: 10.0 m^3,
- spreading width of 2.80 m, with an option of closing one half of the width,
- the spreading rate at constant displacement of the beam is dependent on the speed of the transport chain and proportioning screw located in the spreading cantilever.

5. Description of the recycling procedure

The rehabilitation of pavement structure starts by spreading the 0/4 crushed stone material over the existing pavement structure in an average thickness of 5 cm (Figure 4). This is followed by spreading the cement over the aggregate in the quantity as specified in the initial job-mix formula (Figure 5). Then the recycler is used to mill the existing pavement surface with the 0/4 crushed stone aggregate down to the depth of 18 cm. During the recycling process, the recycler pushes in front of him the water truck and the bitumen truck, which are joined together by pushing tubes. The water and hot bitumen is added to the milled material in the cutting drum. The recycler is followed by the vibratory roller which pre-compacts the recycled mix. The mix is then levelled by grader to the required lines and levels (Figure 6).

The above procedure results in a recycled base course 23 cm in thickness, stabilised with hydraulic binder and foamed bitumen. The thickness of the base course was checked on a daily basis, Figure 7.

Figure 4. Spreading crushed aggregate over the existing pavement

Figure 5. Spreading cement over the crushed aggregate

Figure 6. Recycled mix pre-compacting

Figure 7. Checking thickness of the pavement base course

Figure 8 shows the cross-section of the existing pavement structure before rehabilitation, the procedure used for constructing the base course with 0/4 mm crushed stone material sprinkled with cement, asphalt and clayed subbase crushed stone, and the final cross-section of pavement structure after rehabilitation. The construction of the stabilized base course is followed by placing the asphalt base course BNS 22 B 50/70, 6 cm in thickness, and the asphalt wearing course AB 11 E PmB 45/80-65, 4 cm in thickness.

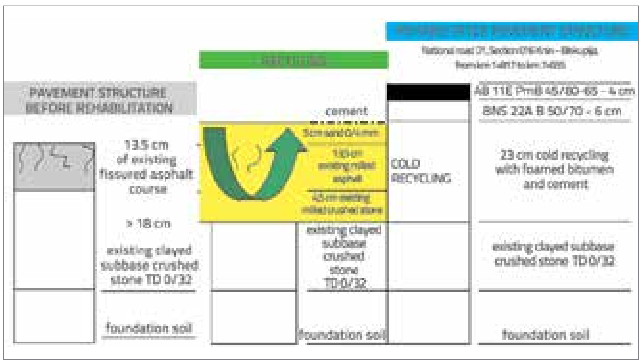


Figure 8. Pavement cross-section prior to and after rehabilitation [9]

6. Quality control

The following items were checked in the scope of on-site control tests:

- quantity of cement spread per square meter of recycled pavement structure,
- recycling depth,
- foamed bitumen temperature and properties.

Recycled layer samples were taken during realization of the works to enable on-site control testing. Recycled mix samples prepared for the testing are shown in Figure 9. The following design parameters are used for pavement structures rehabilitated using the cold recycling procedure with foamed bitumen and cement:

- indirect dry tensile strength (dry sample) ITSs ≥ 200 kPa,
- indirect wet tensile strength (water-saturated sample) ITSm ≥ 100 kPa,

Figure 9. Recycled mix samples prepared for testing

- ITSm / ITSs ratio ≥ 50 %,
- bitumen added to the mix: 2.5 % (Table 2),
- pavement course thickness without asphalt surfacing: 23 cm (Table 2),
- compaction level: min ≥ 98 % [2, 3].

It was established during the recycled layer testing that the quality of the stabilized recycled layer containing foamed bitumen and cement is compliant with technical requirements specified in the pavement structure design. The following results were obtained by testing parameters relevant for the rehabilitated pavement structure:

Indirect tensile strength (ITS)

Some deviations from the mean compressive strength values specified for dry and wet samples in the initial job-mix formula were noted. The compressive strength of wet and dry samples was tested on the total of 54 samples. The minimum and maximum mean tensile strength values for the wet sample (ITS_m) are 219 kPa and 444 kPa, respectively, while the corresponding value specified in the initial job-mix formula is 429 kPa. The minimum and maximum mean tensile strength values for the dry sample (ITS_s) are 309 kPa and 629 kPa, respectively, while the corresponding value specified in the initial job-mix formula is 553 kPa. The minimum and maximum mean tensile strength values for the wet and dry samples, ITS_m / (ITS_s, amount to 67.9 % and 78.0 %, respectively. The indirect tensile strength ratio for dry and wet samples, specified in the job-mix formula, amounts to 78 %.

All realized, minimum, maximum and mean tensile strength values of samples are presented, together with standard deviations, in Table 4. The mean indirect tensile strength value of the water saturated sample (ITS_m) amounts to 374 kPa, which is compliant with requirements specified in the pavement structure design (min. 100 kPa). The mean indirect tensile strength value of the dry sample (ITS_s) amounts to 520 kPa, which is compliant with requirements specified in the pavement structure design (min. 200 kPa). The indirect tensile strength ratio for dry and wet samples , ITS_m / (ITS_s amounts to 72.1 %, which is compliant with requirements specified in the pavement structure design (min. 50 %).

Proportion of paving bitumen

Although the proportion of paving bitumen in the recycled mix amounts to 2.5 % according to the initial job-mix formula, the realized mean proportion of paving bitumen amounts to 4.8 % (Table 4). The mean proportion of bitumen amounts to 4.8 %, and the testing was conducted in accordance with HRN EN 12697-1 [11]. This significant increase in the paving bitumen proportion with regard to the proportion set in the initial job-mix formula is due to the use of recycled mix of smaller gradation at the construction site (Figure 10). The change in the recycled mix grading is due to the mechanical milling technology applied, and variability in the composition of the existing pavement layers.

Table 4. Indirect tensile strengths (ITS) [12]

Sampling date	Sampling location	Proportion of bitumen added to mix	ITS_m [kPa]	ITS_s [kPa]	ITS_m / ITS_s	Cement content [%]	Moisture content [%]	Layer thickness [cm]
23.10.2011.	km 5+700	5,5 %	371,359,362 364	483,479,455 472	77,1 %	1,44	4,2	23
24.10.2011.	km 5+460	5,3 %	373,391,378 381	514,482,503 500	76,2 %	1,54	4,7	23
25.10.2011.	km 5+380	4,9 %	386,396,417 400	532,554,555 547	73,1 %	1,63	4,8	22
26.10.2011.	km 5+210	4,0 %	380,392,361 378	539,561,540 547	69,1 %	1,65	5,7	23
28.10.2011.	km 5+000	3,6 %	342,342,332 339	413,441,448 434	78,0 %	1,52	5,2	23
30.10.2011.	km 4+800	4,8 %	369,343,358 357	480,498,512 497	71,8 %	1,42	5,7	22
05.11.2011.	km 4+620	4,0 %	224,229,204 219	302,317,309 309	70,8 %	1,35	5,9	22
06.11.2011.	km 4+520	4,2 %	353,374,338 355	506,515,518 513	69,2 %	1,65	5,1	23
08.11.2011.	km 4+260	4,2 %	376,410,360 382	570,556,542 556	68,7 %	1,51	5,1	23
10.11.2011.	km 4+000	5,8 %	421,450,372 414	572,586,586 581	71,3 %	1,63	5,9	24
10.11.2011.	km 3+960	5,8 %	433,468,432 444	630,602,655 629	70,6 %	1,59	4,3	23
26.11.2011.	km 3+780	4,4 %	397,400,411 403	498,468,498 488	82,5 %	1,43	6,2	23
27.11.2011.	km 3+570	4,9 %	391,397,431 406	587,577,586 583	69,7 %	1,64	6,5	23
28.11.2011.	km 3+380	5,9 %	392,381,354 376	504,493,491 496	75,7 %	1,53	5,9	23
06.12.2011.	km 2+600	4,6 %	365,362,348 358	504,494,513 504	71,1 %	1,51	4,8	23
07.12.2011.	km 2+210	4,9 %	405,379,395 393	578,553,519 550	71,5 %	1,56	4,6	23
09.12.2011.	km 1+860	4,5 %	389,404,388 394	589,592,587 589	66,8 %	1,59	5,8	23
13.12.2011.	km 1+620	4,2 %	370,399,367 379	550,577,545 557	67,9 %	1.51	5,7	23
Arithmetic mean		4,8 %	374	520	72,1 %	1,54 %	5,3	22,9
Minimum value		3,6 %	204	302	66,8 %	1,35 %	4,2	22
Maximum value		5,9 %	450	655	82,5 %	1,65 %	6,5	24
Standard deviation		0,689	45,268	71,2947	4,1043	0,0880	0,6734	0,4715
Standard deviation from arithmetic mean		0,1624	10,6699	16,8045	0,9674	0,0207	0,1587	0,1111

Table 5. Compaction level determined by volumeter [12]

Date of sampling	Sampling location	Dry sample density (volumeter) [t/m³]	Dry sample density (Proctor) [t/m³]	Compaction level [%]
23/24.10.2011.	5+700L/5+750L	2,062	2,030	98,4
24/25.10.2011.	5+460L/5+445L	2,076	2,236	107,7
25/26.10.2011.	5+380L/5+340L	2,091	2,222	106,3
26.10./02.11.	5+210L/5+180L	2,179	2,172	99,7
28.10./02.11.	5+000L/4+900L	2,137	2,186	102,3
30.10./02.11.	4+800L/4+730D	2,107	2,077	98,6
05/08.11.2011.	4+620D	2,121	2,132	100,5
06/08.11.2011.	4+520D	2,135	2,182	102,2
08/11.11.2011.	4+260	2,108	2,247	106,6
26/28.11.2011.	3+780L	2,136	2,299	107,6
27/28.11.2011.	3+570	2,132	2,213	103,8
28/30.11.2011.	3+380	2,111	2,089	99,0
06/07.12.2011.	2+600	2,152	2,163	100,5
07/08.12.2011.	2+210	2,092	2,149	102,7
09/12.12.2011.	1+860	2,158	2,202	102,0
13/14.12.2011.	1+620	2,161	2,148	99,4
Arithmetic mean		2,122	2,172	102,3
Minimum value		2,062	2,030	98,4
Maximum value		2,179	2,299	107,7
Standard deviation		0,0324	0,0683	3,1326
Standard deviation from arithmetic mean		0,0020	0,0171	0,1958

Layer thickness

An average thickness of the recycled base course stabilized with foamed bitumen and cement amounts to 22.9 cm (Table 4), which is in accordance with the permitted deviation of +/- 10 %.

Compaction level by volumeter

The mean level of compaction determined by volumeter amounts to 102.3 % which is compliant with requirements set in the pavement structure design (min. ³ 98 %). Compaction level values and standard deviations are presented in Table 5.

Recycled mix extraction

After extraction of paving bitumen in laboratory from mix samples taken at the construction site, and during realization of the cold recycling procedure, an average grading curve was determined in accordance with HRN EN 933-1 (Figure 10). The total of 54 samples was processed, as shown in Table 4.

It can be seen in Figure 10 that an average grading of recycled mix samples greatly deviates from the initial laboratory composition shown in Figure 2. The average grading curve obtained by extraction presents much smaller gradation when compared with the design laboratory mix. The gradation of the realized recycled mix amounts to 0/22.4 mm, and it contains 14.3 % of grains passing through the sieve size 0.063 mm.

7. Conclusion

According to the data about positive experience in the use of pavement structure rehabilitation technology based on cold recycling by foamed bitumen and cement, it may realistically be expected that this pavement rehabilitation procedure will be widely accepted in current practice. In case of road rehabilitation and renewal by traditional procedure,

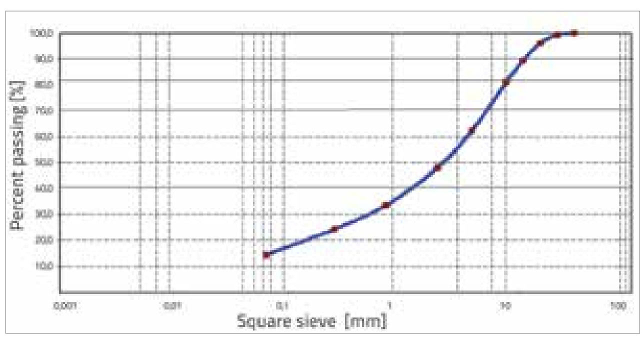


Figure 10. Average extraction of the recycled mix [12]

the problem of waste asphalt is not solved, but rather this material is permanently stored at disposal sites. That is why it is indispensible to apply environmentally friendlier methods in which a significant percentage of waste from existing pavements is actually reused. Recycling brings many benefits in terms of economy and environmental protection, savings made to natural mineral raw materials, and savings of space needed for permanent or temporary disposal of waste material generated by traditional methods. Pavement rehabilitation based on this technological procedure shortens the transport time as the excavated material is not transported to another location, and no new natural stone material is supplied to the site.

The pavement rehabilitation technology described in this paper enables proper rehabilitation of pavement structures which, upon such remedy, present the required resistance to freezing, adequate bearing capacity and are monolithic, as the work is realized in a single layer. To confirm the above statements, this road will be monitored, which includes visual inspection of cracking, deflexion inspection by falling weight deflectometer (FWD), and international roughness index (IRI) measurements.

REFERENCES

[1] The Asphalt Handbook, Manual Series No.4 /MS-4/ Seventh Edition, Asphalt Institute, USA, 2007.

[2] Wirtgen Cold Recycling Manual, 2nd Edition, 2004.

[3] Wirtgen Cold Recycling Manual, 3th Edition, 2010.

[4] Miljković, M.: Hladna reciklaža na licu mesta asfaltnih kolovoznih konstrukcija uz primenu penastog bitumena kao veziva, Put i saobraćaj, (2009) 2, 18-24.

[5] Primorje d.d.: Tehnološki elaborat za prethodni radni sastav (recepturu) za hladnu reciklažu s cementom i upjenjenim bitumenom, Ajdovščina, travanj 2011.

[6] Sršen, M., Kovačić, M., Kaučić, D.: Determining soil freez ing depth under the pavement structures, GRADEVINAR 56 (2004) 3, 145-154 (in Croatian).

[7] HRN EN 933-1: Ispitivanje geometrijskih svojstava agregata -1. dio: Određivanje granulometrijskog sastava – Metoda sijanja (EN 933-1:1997/A1:2005)

[8] HRN.U.B1.018:1980 Geomehanička ispitivanja. Određivanje granulometrijskog sastava

[9] Radni sastav (receptura) za hladnu reciklažu s cementom i upjenjenim bitumenom, Primorje d.d., Ajdovščina, 14. 09. 2011.

[10] HRN EN 13286-2: Nevezane i hidrauličnim vezivom vezane mješavine - 2. dio: Ispitne metode za određivanje laboratorijske referencijske gustoće i udjela vode – Zbijanje po Proctoru (EN 13286-2:2004)

[11] HRN EN 12697-1: Bitumenske mješavine - Ispitne metode za asfalt proizveden vrućim postupkom - 1. dio: Topljivi udio veziva (EN 12697-1:2000+AC:2001)

[12] Završni izvještaj o kvaliteti izvođenja hladne reciklaže s cementom i upjenjenim bitumenom, Osijek-Koteks, Osijek, 20.12. 2011.