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Properties of unbound base course mixes with recycled asphalt

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Preliminary report

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The possibility of using recycled asphalt as replacement for natural aggregate in unbound base course mixes is explored in the paper. The mixes in which a certain proportion of natural aggregate (limestone, gravel) was replaced with recycled asphalt were analysed. The testing program involved analysis of the grading, compaction parameters, physicomechanical properties and bearing capacity of mixes. The results show that recycled asphalt can be used, in some proportions, as a suitable replacement for natural aggregate.

Key words:
unbound base course, recycled asphalt, grading, physicomechanical properties, bearing capacity

Prethodno priopćenje

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Svojstva mješavina za izradu nevezanih nosivih slojeva s dodatkom recikliranog asfalta

U radu je istražena mogućnost primjene recikliranog asfalta kao zamjene za prirodni agregat u mješavinama za izradu nevezanih nosivih slojeva. Istraživanje je provedeno na mješavinama u kojima je određeni udio prirodnog agregata (vapnenca, šljunka) zamijenjen recikliranim asfaltom. Programom istraživanja obuhvaćena su ispitivanja granulometrijskog sastava, parametara zbijanja, fizikalno-mehaničkih svojstava i nosivosti mješavina. Rezultati pokazuju da reciklirani asfalt, u određenom udjelu, može biti prikladna zamjena za prirodni agregat.

Ključne riječi:
nevezani nosivi sloj, reciklirani asfalt, granulometrijski sastav, fizikalno-mehanička svojstva, nosivost

Vorherige Mitteilung

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Eigenschaften von Mischungen mit recykliertem Asphalt zur Ausführung unabhängiger Tragschichten

In dieser Arbeit wird die mögliche Anwendung recykierten Asphalts als Ersatz für natürliche Gesteinskörnung in Mischungen zur Ausführung unabhängiger Tragschichten erforscht. Die Untersuchungen wurden an Mischungen durchgeführt, bei denen ein Anteil natürlicher Gesteinskörnung (Kalkstein, Kies) mit recykliertem Asphalt ersetzt wurde. Das Forschungsprogramm umfasste die Ermittlung der granulometrischen Zusammensetzung, der Verdichtungsparameter sowie der physikalisch-mechanischen Eigenschaften und der Tragfähigkeit der Mischungen. Aufgrund der Resultate zeigt sich, dass rezyklierter Asphalt in bestimmtem Anteil als angemessener Ersatz für natürliche Gesteinskörnung angesehen werden kann.

Schlüsselwörter:
unabhängige Tragschichten, recyklierter Asphalt, granulometrische Zusammensetzung, physikalisch-mechanische Eigenschaften, Tragfähigkeit

1. Introduction

Asphalt mixtures are used for construction of pavement wearing courses on more that ninety percent of the road network in Europe [1] and, according to some sources, the situation is quite similar in other parts of the world [2]. In accordance with this trend, asphalt mixtures are used for construction of pavement wearing courses on almost the entire road network in Croatia [3]. More than 50 million tons of recycled asphalt are produced each year during the maintenance and rehabilitation of asphalt pavements in Europe [4], and as many as 100 million tons in the USA [5].

Recycled asphalt is most often used as a replacement for natural aggregate in mixtures for construction of asphalt pavement courses (wearing, binder and base) and, in this respect, cold or hot recycling procedures are applied, either in-place or in-plant. Considering top limits for allowable proportion of recycled asphalt, and other requirements concerning asphalt mixtures and courses made of such mixtures, there are still considerable quantities of recycled asphalt that can not be reused in this way [6]. Consequently, alternative solutions have to be found to avoid recycled asphalt disposal costs, i.e. to prevent its illegal dumping. One of possible alternatives is to use this material as replacement for natural aggregate in unbound base courses.

Research on possible use of recycled asphalt in unbound base courses has been in progress since the mid 1990s. Most researchers have confirmed that this material can be used, in an appropriate proportion, as a suitable replacement for natural aggregate. The quality requirements applied for recycled asphalt and natural aggregate mixtures are similar to those applied for natural aggregate [7].

Although the use of recycled asphalt in unbound base courses is considered inferior when compared to its use in asphalt courses, this method of using recycled asphalt has nevertheless gained in popularity because it is a material recovery technique, and because of its favourable environmental effects (conservation of natural resources, minimisation of waste), and economic benefits. However, because of the lack of systemic laboratory and field tests, and due to problems that occur during sporadic use of such mixtures, they have still not been accepted as a standard material for construction of unbound base courses [6, 8- 10].

The influence of recycled asphalt and natural aggregate type on physical-mechanical properties, compaction parameters, and bearing capacity of mixtures for construction of unbound base courses, is studied in this paper, and the quality of mixture is estimated taking into account requirements specified in General Technical Requirements for Road Works (OTU) [11].

2. Experimental analysis

Testing program, harmonized with the corresponding OTU requirements [11], was conducted in order to estimate possibilities for using the recycled asphalt and natural aggregate mixtures for the construction of unbound base courses. The testing program was divided into two phases: definition of mixture composition and laboratory testing.

2.1. Definition of mixture composition

According to OTU requirements, the use of natural stone aggregate is allowed in the construction of unbound base courses. Taking this into account, the research was conducted on recycled asphalt and limestone, as well as on recycled asphalt and gravel mixtures. The following basic materials were used in the preparation of the mixtures:

- recycled asphalt obtained by mechanical milling (R), (Ceste Karlovac d.o.o.);
- limestone (V), fractions 0/4, 4/8, 8/16, and 16/32 (Zvečaj Quarry – ARKADA d.o.o.);
- gravel (S), fractions 0/4, 4/8, 8/16, and 16/32 (Motičnjak Gravel Pit – COLAS Hrvatska d.o.o.);

Table 1. Particle size distribution results for basic materials

Basic material	Limestone (V)				Gravel (S)				Recycled asphalt (R)
	0/4	4/8	8/16	16/32	0/4	4/8	8/16	16/32	
Sieve size [mm]	Passing [%]								
22.4				66.74				63.46	90.11
16.0			94.42	18.70			94.10	7.74	76.95
8.0		95.81	9.85	0.86		80.38	2.72	0.57	43.36
4.0	98.47	31.94	0.56	0.81	88.62	2.29	0.51		17.72
2.0	73.04	4.30	0.52		66.18	0.63	0.47		6.44
1.0	44.18	4.26	0.50		55.74				2.11
0.500	26.67	4.20			47.72				0.71
0.250	16.89	4.16			26.18				0.30
0.125	11.83	4.11			4.38				0.16

Table 2. Proportion of recycled asphalt and natural aggregate fraction in designed mixtures

Mixture label		V100R0	V80R20	V65R35	V50R50	S100R0	S80R20	S65R35	S50R50
Proportion of basic materials in the mixture [%]									
Recycled asphalt (R)		0	20	35	50	0	20	35	50
Natural aggregate (V; S)	16/32	20	15	10	10	15	15	10	5
	8/16	10	5	5	0	20	10	5	0
	4/8	25	20	10	5	20	10	5	5
	0/4	45	40	40	35	45	45	45	40

After selection of basic materials, which is the first step in the definition of mixture composition, their particle size distribution (grading) was tested according to HRN EN 933-1 [12] (Table 1). It can be seen from graphical presentation of the particle size distribution for recycled asphalt (Figure 1) that the grading curve greatly deviates from the OTU defined limit grading area, which points to the fact that the recycled asphalt can be used in construction of unbound base courses only after appropriate particle size distribution corrections are made.

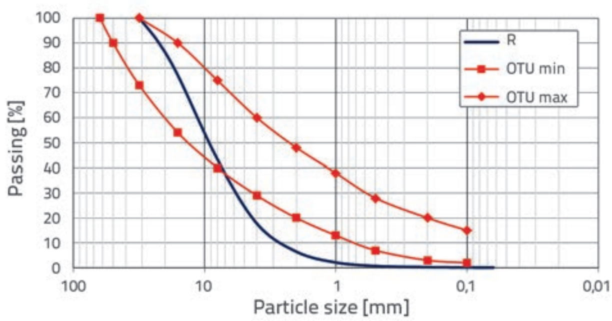

Figure 1. Particle size distribution of recycled asphalt

In order to obtain mixtures that are compliant with the grading requirements, a mix design procedure was conducted with the purpose of replacing a proportion of recycled asphalt in the total weight of the mixture with natural aggregate. It was established during the design procedure that the maximum proportion of recycled asphalt that would be compliant with grading requirements for construction of unbound base courses amounts to 50 % . A total of eight mixtures were designed. In these mixtures, the proportion of recycled asphalt (0, 20, 35 and 50 %) as well as the type and proportion of natural aggregate fractions were varied. The proportion of recycled asphalt and natural aggregate fractions in the designed mixtures is presented in Table 2.
Mixtures (shown in Figure 2) were prepared according to the designed composition, and the particle size distribution testing was conducted. Test results for all eight mixtures, and the limit grading values, are shown in Table 3. The following grading-related properties were also determined: maximum grain size, uniformity coefficient, and content of grains smaller than 0.02 mm. The values obtained and relevant OTU requirements are presented in Table 4.
Based on the above results (grading curve, maximum grain size, uniformity coefficient, proportion of grains smaller than

Figure 2. Recycled asphalt mixed with limestone (left) and gravel (right)

Table 3. Grading of recycled asphalt and natural aggregate mixtures

Mixture label	V100R0	V80R20	V65R35	V50R50	S100R0	S80R20	S65R35	S50R50	OTU request
Sieve size [mm]	Passing [%]								
31.5	100	100	100	100	100	100	100	100	73-100
22.4	91.64	94.23	94.80	92.03	93.57	91.96	91.75	90.61	-
16.0	83.25	83.03	81.74	76.74	84.09	80.27	81.14	78.69	54-90
8.0	70.46	66.75	61.88	54.37	61.54	60.34	61.74	61.33	40-75
4.0	52.49	47.24	47.24	41.93	40.52	42.66	44.64	44.13	29-60
2.0	34.68	30.57	31.88	28.81	30.15	31.15	30.10	31.36	20-48
1.0	20.80	18.07	18.44	17.13	25.50	25.75	23.00	24.65	13-38
0.500	12.89	11.18	11.25	10.28	22.04	22.05	19.02	20.57	7-28
0.250*	8.49	7.34	7.27	6.61	11.90	12.34	9.76	11.41	3-20
0.125*	6.03	5.13	5.03	4.56	1.92	2.26	1.58	2.14	2-15
0.063	5.46	4.69	4.66	4.20	0.89	1.14	1.10	1.14	-

* Percent passing through 0.2 and 0.1 mm sieves is specified in OTU

Table 4. Grading properties of recycled asphalt and natural aggregate mixtures

Mixture label	V100R0	V80R20	V65R35	V50R50	S100R0	S80R20	S65R35	S50R50	OTU request
Maximum grain size [mm]	31.5	31.5	31.5	31.5	31.5	31.5	31.5	31.5	≤63
Uniformity coefficient $U = d_{60}/d_{10}$	16.87	15.76	17.78	20.83	34.12	35.88	29.65	33.29	15-50* 15-100
Proportion of grains smaller than 0.02 mm [%] **	3.28	<3.28	<3.28	<3.28	<0.89	<1.14	<1.10	<1.14	3

* 15 to 50 for crushed stone material; 15 to 100 for gravel

** hydrometer analysis for determining the proportion of grains smaller than 0.02 mm was conducted for mixtures V100R0 that had the highest percentage of grains smaller than 0.063 mm, and it was assumed that other limestone and recycled asphalt mixtures have a smaller proportion of grains than the obtained 3.28 %; as in gravel mixtures the proportion of grains smaller than 0.063 mm is smaller than the required 3%, the hydrometer analysis was not conducted for these mixtures

0.02 mm), it can be concluded that, as to their grading, all eight mixtures meet requirements set for materials for the construction of unbound base courses.

2.2. Laboratory testing of mixtures

The above defined recycled asphalt and natural aggregate mixtures were subjected to laboratory testing in order to determine their physical-mechanical properties, compaction parameters and their bearing capacity. The fractions of basic materials were subjected to testing so as to determine their physical-mechanical properties; shape of coarse aggregate [13], water absorption [14], loose grains content [15], and resistance to abrasion according to the Los Angeles (LA) method [16]. Physical-mechanical properties of mixtures were then determined based on the proportion of individual fractions. All these tests were conducted in accordance with the currently applicable standards.

The modified Proctor test based on HRN EN 13286-2 [17] was conducted to determine basic compaction parameters, maximum dry density, and optimum water content. Because of the maximum grain size, the decision was made to select the compaction method involving a large mould (B), 4.5 kg hammer (B), and 45.7 cm drop height. The bearing capacity testing, expressed by means of the CBR ratio, was conducted according to HRN EN 13286-47 [18] using samples compacted based on the modified Proctor procedure at optimum water content.

3. Analysis of test results

Test results were analysed with regard to the type of natural aggregate and the proportion of recycled asphalt in the mixture. The test results were compared with the OTU requirements for mixtures that are used for construction of unbound base courses [11].

3.1. Physical-mechanical properties

The suitability of an aggregate for use in unbound base courses is proven by testing its physical-mechanical properties. The permanence of mechanical properties of the unbound base course during use of the pavement is ensured by fulfilling requirements regarding the shape of coarse aggregate, water absorption, loose grains content, and resistance to abrasion.

3.1.1. Shape of coarse aggregate – proportion of unfavourably shaped grains

According to OTU, the proportion of unfavourably shaped grains (3:1) must not exceed 40 %. Test results have revealed that the proportion of unfavourably shaped grains ranges from 4.9 to 14.7 % in recycled asphalt and limestone mixtures, and from 9.8 to 17.2 % in recycled asphalt and gravel mixtures. The influence of the proportion of recycled asphalt on the proportion of unfavourably shaped grains is presented in Figure 3. Considering the type of natural aggregate, it can be seen that gravel mixtures have a greater content of unfavourably shaped grains compared to mixtures with limestone. The proportion of unfavourably shaped grains increases with an increase in the proportion of recycled asphalt, which is more pronounced in mixtures with limestone compared to mixtures with gravel. Such trend is due to great difference in the proportion of unfavourable shaped grains between recycled asphalt and limestone, while these differences between the gravel and recycled asphalt are only pronounced in fraction 16/32. By increasing the proportion of recycled asphalt from 0 % to 20, 35 and 50 % , the proportion of unfavourably shaped grains increases by 79, 140, and 200 % for mixtures with limestone, i.e. by 31, 53, and 76 % for mixtures with gravel.

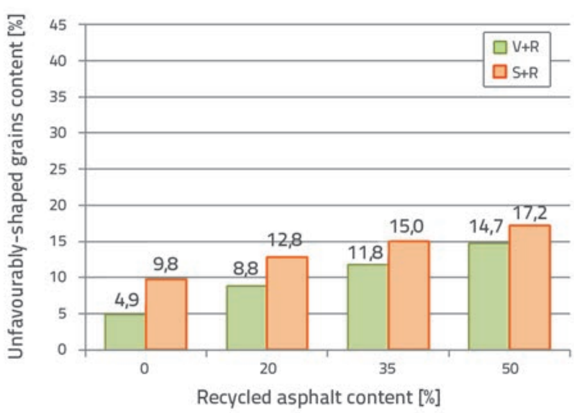

Figure 3. Proportion of unfavourably shaped grains as related to recycled asphalt content

Despite the negative influence of the proportion of recycled asphalt on the proportion of unfavourably shaped grains, this influence is below the allowed maximum of 40 % in case of all mixtures.

3.1.2. Water absorption

According to OTU, the maximum percentage of water absorption is 1.6 % for granular stone materials used in the production of unbound base courses. The testing has revealed that the water absorption varies from 0.4 to 0.8 % for the recycled asphalt and limestone mixtures, and from 0.8 to 1 % for the recycled asphalt and gravel mixtures. The influence of the proportion of recycled asphalt on water absorption is presented in Figure 4. Considering the type of natural aggregate, it can be seen that gravel mixtures have a greater water absorption capability compared to mixtures with limestone. Water absorption increases with an increase in the proportion of recycled asphalt in the mixtures, and the influence of recycled asphalt on the affinity of mixtures toward water absorption is more pronounced in mixtures with limestone compared to mixtures with gravel. By increasing the proportion of recycled asphalt from 0 % to 20, 35 and 50 % in mixtures with limestone, the water absorption increases by 25, 75, and 100 %. In case of mixtures with gravel, the change in the proportion of recycled asphalt from 0 % to 20 and 35 % results in the 12.5 % increase in water absorption, while this increase amounts to 25 % when the proportion is changed from 0 % to 50 %.

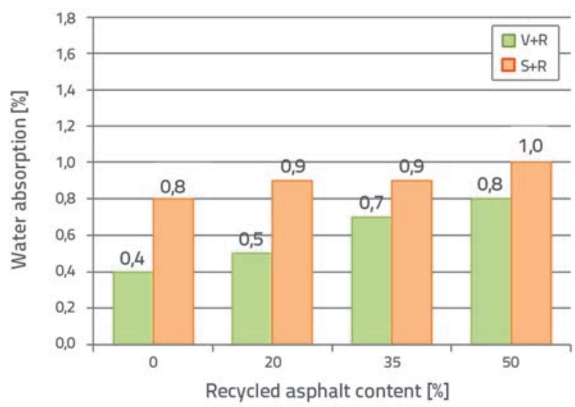

Figure 4. Water absorption as related to recycled asphalt content

Because of hydrophobic properties of bitumen, it may be expected that the recycled asphalt will exhibit a lower water absorption capability compared to natural aggregate. The results obtained are in accordance with the previous research conducted by Locander [19]. To explain these results, it would be necessary to conduct further testing to determine the bitumen content, pore volume for natural and recycled aggregate, as well as the volume of pores filled with bitumen. In all mixtures tested, water absorption was lower than the maximum allowed 1.6 % .

3.1.3. Loose grains content

According to OTU, the proportion of loose grains in the mixtures for construction of unbound base courses should not exceed 7 %. For natural aggregate used in the research, the proportion of loose grains amounted to zero, i.e. all loose grains in the mixtures are the grains originating from recycled asphalt (Figure 5). The proportion of loose grains increased with an increase in the proportion of recycled asphalt in the mixture. The proportion of loose grains in the mixtures with 20 % of recycled asphalt amounted to 3.9 %. By further increasing the proportion of recycled asphalt to 35 % and 50 % , the proportion of loose grains increases on an average by 72 % and 146 %, respectively.

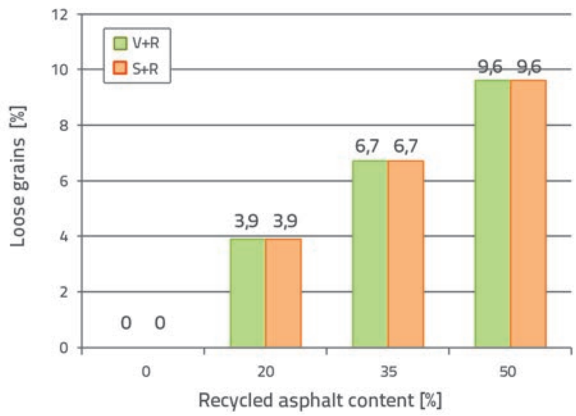

Figure 5. Proportion of loose grains as related to recycled asphalt content

The mixtures with 50 % of recycled asphalt do not comply with the criterion for maximum proportion of loose grains (7 %).

3.1.4. Resistance to abrasion according to Los Angeles method

According to OTU, the maximum Los Angeles abrasion value is 45 % for aggregates that are used for construction of unbound base courses. Test results show that the LA values range from 19.6 to 19.7 % for mixtures with limestone, and from 22.5 to 25.2 % for mixtures with gravel. The influence of the recycled asphalt content on the LA value is shown in Figure 6.

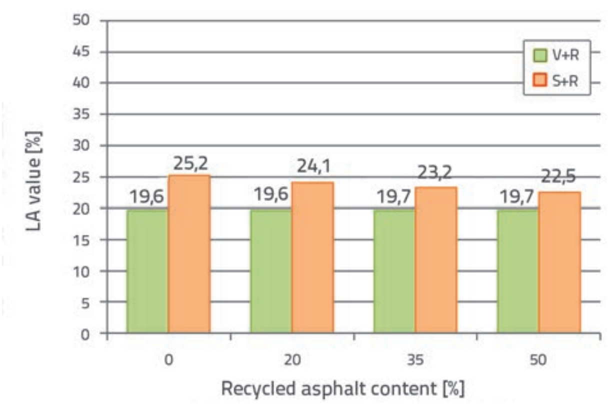

Figure 6. LA value as related to recycled asphalt content

Considering the type of natural aggregate, it can be seen that Los Angeles values are higher in gravel mixtures compared to mixtures with limestone. The proportion of recycled asphalt does not greatly influence the change in LA value for limestone mixes, which could have been expected as the aggregate used in the preparation of asphalt mixture is of limestone origin, and comes from the same source as the limestone used in the research. Considering resistance to abrasion expressed by the LA value, it can be concluded that the properties of recycled asphalt are similar to that of limestone. These results are in harmony with the results obtained by Locander [19] and Mokwa and Peebles [20]. In case of mixtures with gravel, the LA value decreases with an increase in recycled asphalt content in the mixture. By increasing the proportion of recycled asphalt from 0 % to 20, 35 and 50 %, the LA values decrease by 4, 8 and 11 %, respectively. In all mixtures, the Los Angeles value was lower than the maximum allowed value of 45 %.

Based on these results, it can be concluded that the tested mixtures, with the exception of the ones with 50 % of recycled asphalt that do not meet the maximum loose grains requirement, are adequate – considering their physical-mechanical properties - for construction of unbound base courses.

3.2. Compaction parameters

The compaction of granular stone aggregate during construction of unbound base course gives best results at an optimum water content, i.e. at the quantity of water that enables maximum level of compaction at the compaction energy released during the modified Proctor procedure. Proctor curves that define the relationship between the water content and dry unit weight were determined for all eight mixtures (Figure 7).

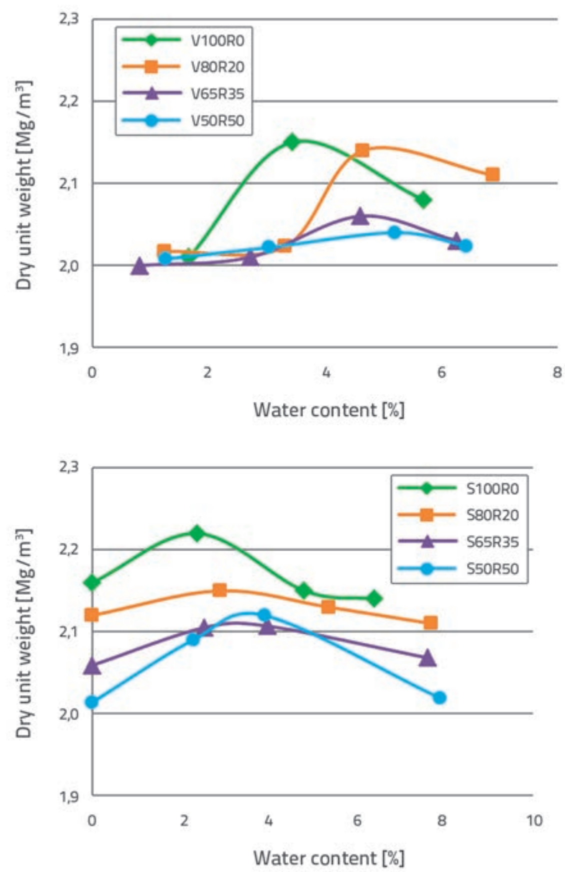

Figure 7. Proctor test results

The optimum water content and maximum dry density values were determined by reading maximum values from the Proctor curve. The influence of the recycled asphalt content on the optimum water content and maximum dry density is presented in Figures 8 and 9.

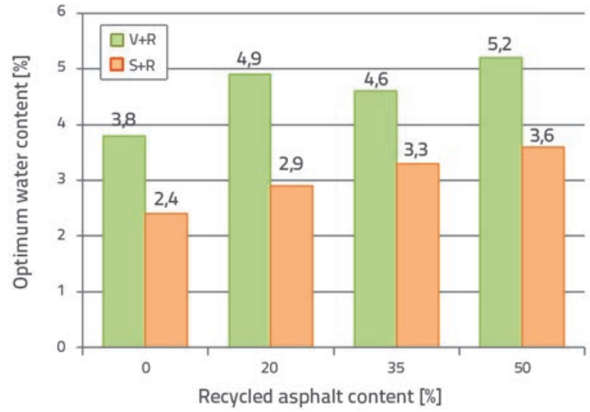

Figure 8. Optimum water content as related to recycled asphalt content

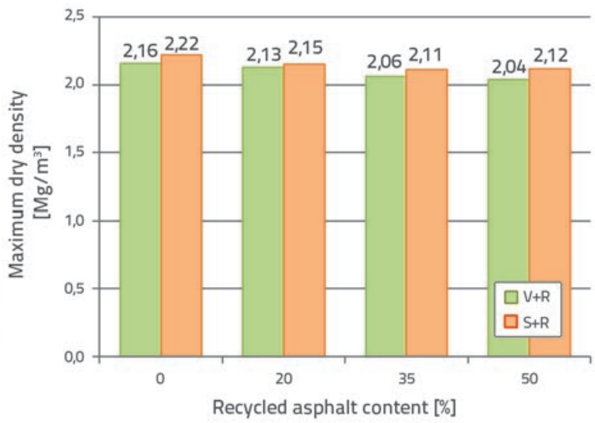

Figure 9. Maximum dry density as related to recycled asphalt content

Higher values of optimum water content were obtained for mixtures with limestone compared to the ones with gravel (Figure 8). The value of an optimum water content increases for all tested mixtures with an increase in the recycled asphalt content. Such results are in accordance with earlier studies made by Alam et al. [21], Attia and Abdelrahman [22], and Taha et al. [23], and they may be the consequence of the change in particle size distribution. During compaction an increase in the number of small particles with an increase in the recycled asphalt content in the mixtures occurred which resulted in higher optimum water content. By an increase in recycled asphalt content from 0 % to 20, 35, and 50 %, the value of an optimum water content increases by 29, 21, and 37 % for mixtures with limestone, i.e. by 21, 38 and 50 % for mixtures with gravel.

It can be seen from test results that the mixtures with gravel have a higher maximum dry density compared to the mixtures with limestone (Figure 9). The value of maximum dry density reduces with an increase in the recycled asphalt content in the mixture. These results are in accordance with earlier studies made by Lou [24], Taha et al. [23], and Bennet and Maher [25], and they are due to lower specific density of recycled asphalt compared to natural aggregate. By increasing the recycled asphalt content from 0 % to 20, 35, and 50 % , the maximum dry density reduces to 1.39, 4.63 and 5.56 % in mixes with limestone, i.e. to 3.15, 4.95, and 4.50 % in mixtures with gravel. Modified Proctor test results were used during preparation of samples for determination of the California bearing ratio (CBR).

3.3. Bearing capacity

The bearing capacity of granular stone material is normally estimated in laboratory by means of the California bearing ratio testing. The influence of the recycled asphalt content on the bearing capacity of tested mixtures is shown in Figure 10. The CBR values of limestone mixtures without recycled asphalt are by 72 % higher compared to gravel mixtures without recycled asphalt. Figures 10 and 11, show that the CBR values tend to decrease with an increase in the recycled asphalt content in mixtures, regardless of the type of natural aggregate.

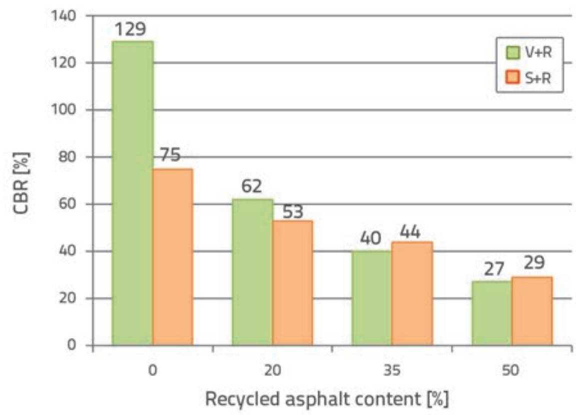

Figure 10. CBR value as related to recycled asphalt content

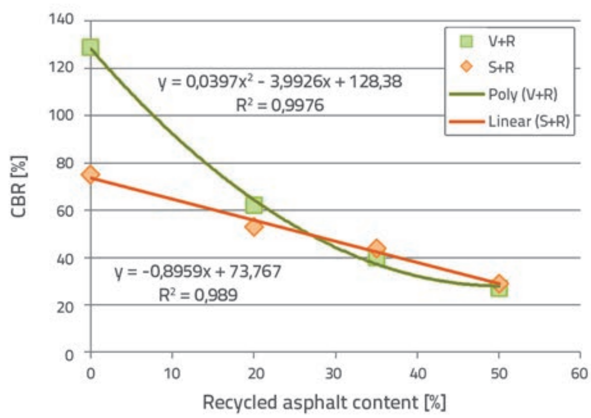

Figure 11. Correlation between CBR and recycled asphalt content

These results are compliant with previous studies [23, 25-28], and they are due to higher compressibility of recycled asphalt compared to natural aggregate. Although the bearing capacity reduction trend is clear and well defined, tests have shown that the rate of reduction in CBR with an increase in the recycled asphalt content greatly depends on the properties of natural aggregate. The CBR value changes almost linearly with an increase in recycled asphalt content in case of mixtures with gravel, while this trend can be described by the second-degree polynomial for mixtures with limestone (Figure 11).

By increasing the recycled asphalt content from 0 % to 20, 35 and 50 %, the CBR value reduces by 52, 69, and 79 % in mixtures with limestone, i.e. by 29, 41 and 61 % in mixes with gravel. It can reasonably be assumed that the reduced CBR values are due to bitumen coating of recycled asphalt, which reduces the roughness, and hence lowers the friction between aggregate grains. CBR values in mixtures with 35 % and 50 % of recycled asphalt are of the same order of magnitude regardless of the type of natural aggregate, and so it can be concluded that the influence of natural aggregate on the bearing capacity properties of such mixtures at a particular proportion of recycled asphalt is negligible.

According to OTU [11], the minimum CBR value for crushed aggregate or gravel mixture with more than 50 % of crushed stone material amounts to 80 %, and 40 % for natural gravel or gravel mixtures will less than 50 % of crushed stone material. OTU document does not define bearing capacity requirements for natural aggregate and recycled asphalt mixtures. However, as the resilient modulus tests [29] have shown that the mixes with recycled asphalt perform in the way similar to gravel when exposed to traffic load, these mixtures can be subjected to a single bearing capacity requirement expressed through minimum CBR value of 40 % . Mixtures with the recycled asphalt content of 50 % do not meet this requirement. Considering the CBR values obtained in the testing, it can be concluded that – as to baring capacity – the maximum proportion of recycled asphalt in mixtures for construction of unbound base courses amounts to 35 %.

4. Conclusion

The following features were tested in order to estimate possibilities for using the recycled asphalt and natural aggregate mixtures in the construction of unbound base courses: particle size distribution, compaction parameters (maximum dry density, optimum moisture content), physical-mechanical properties (shape of coarse aggregate, water absorption, loose grains content, LA value), and load bearing capacity as expressed through the CBR value. The tests were conducted on mixtures of two types of natural aggregate, limestone and river gravel, and recycled asphalt obtained by mechanical milling. In mixtures the portion of recycled asphalt was varied in the weight percentages of 0, 20, 35 and 50 % with respect to the natural aggregate content. Test results were compared with requirements that the mixtures for construction of unbound base courses have to meet according to General Technical Requirements for Road Works.

Based on test results and appropriate analyses, the following conclusions can be made with regard to materials used in the research:

- Maximum proportion of recycled asphalt used in this research, i.e. the proportion that would comply with grading requirements for the construction of unbound base courses, amounts to 50 % .
- Mixtures with gravel have a greater content of unfavourably shaped grains when compared to mixtures with limestone. The proportion of unfavourably shaped grains increases with an increase of the recycled asphalt content in mixtures. All mixtures satisfy the criterion on maximum content of unfavourably shaped grains, which is 40 %.
- Gravel and recycled asphalt mixtures exhibit a greater water absorption capacity compared to mixtures with limestone. The water absorption capacity of mixtures increases with an increase in the recycled asphalt content in the mixture. All mixtures satisfy the maximum absorption criterion, which amounts to 1.6 %.
- Natural aggregates used in the testing have no loose grains, and the proportion of loose grains in the mixtures is proportional to the recycled asphalt content. Mixtures with 50 % of recycled asphalt do not meet the criterion on maximum content of loose grains, which amounts to 7 %.
- Recycled asphalt and limestone mixtures have approximately the same LA values regardless of the recycled asphalt content. The LA value decreases with an increase of the recycled asphalt content in mixtures with gravel. All mixtures meet requirements on the maximum allowed LA value, which is 45 %.
- Gravel mixtures exhibit higher maximum dry density values and lower optimum moisture values when compared to mixtures with limestone. The trend involving decrease in maximum dry density and increase in optimum moisture content with an increase in the recycled asphalt content has been observed in all mixtures.
- The CBR value for the recycled asphalt and natural aggregate mixtures decreases with an increase in the recycled asphalt content in the mixture, and the rate of such decrease greatly depends on the type of natural aggregate. The 40 % requirement for minimum CBR values, has not been met by mixtures with 50 % of recycled asphalt.

Based on the analysis of results, and taking into account requirements set by OTU with regard to mixtures for unbound base courses, it can finally be concluded that natural aggregate can be replaced with recycled asphalt in these mixtures, but the recycled asphalt content must be limited to 35 % . The use of recycled asphalt in unbound base courses would constitute a considerable contribution to the preservation of natural non-renewable resources of aggregate, and to a reduced generation of this waste material.

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