

Design and verification of bituminous mixtures with the increased content of reclaimed asphalt pavement

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Abstract. Recycling of bituminous pavements is an issue increasingly being discussed in Poland. The analysis of domestic and foreign experience indicates a need to develop this technology in our country, in particular the hot feeding and production technologies. Various steps are being taken in this direction, including research projects. One of them is the InnGA project entitled: “Reclaimed asphalt pavement: Innovative technology of bituminous mixtures using material from reclaimed asphalt pavement”. The paper presents the results of research involving the design of bituminous mixtures in accordance with the required properties and in excess of the content of reclaimed asphalt permitted by the technical guidelines. It presents selected bituminous mixtures with the content of RAP of up to 50% and the results of tests from verification of industrial production of those mixtures. The article discusses the details of the design process of mixtures with a high content of reclaimed asphalt, the carried out production tests and discusses the results of tests under the verification of industrial production. Testing included basic tests according to the Polish technical requirements of WT-2 and the extended functional testing. The conducted tests and analyses helped to determine the usefulness of the developed bituminous mixtures for use in experimental sections and confirmed the possibility of using an increased amount of reclaimed asphalt up to 50% in mixtures intended for construction of national roads.

Keywords: hot recycling, reclaimed asphalt pavement, RAP, bituminous mixture, asphalt mixing plant

1. Introduction

Nowadays, recycling is an extremely important and common issue. It covers various areas of life and human activity. Protection of the environment, waste reduction and saving of natural resources are the main objectives of recycling. Recycling of asphalt pavements fits very well in such established goals. This technology is increasingly used. The reclaimed asphalt pavement is a valuable material and its composition contains mainly mineral aggregate and asphalt binder. It is the material obtained from milling of bituminous pavements, removal of the old pavement or originating from surplus production [1,2].

Various methods of asphalt pavement recycling are known: both in hot and cold technology [3, 4, 5, 6]. Among the many known methods, the hot recycling technology in the mixing plant is considered to be the most effective and using the value of the recovered raw materials. The hot recycling



technology has been known and used for years worldwide, as well as in Poland [7]. However, it is necessary to differentiate between two variations of this technology. In the first of them the reclaimed asphalt is cold-fed directly to the mixer. In the second, more advanced and efficient one, the reclaimed asphalt is preheated in a special system. Hot recycling is not widely used in Poland, and our plants are dominated by the cold feed method. However, the use of this method is associated with some drawbacks, among which it is necessary to mention restrictions in the amount of reclaimed asphalt added to the bituminous mixture. In many countries, it is quite commonly used and striving for the maximum use of RAP [8, 9, 10].

Application of the recycling technology with hot feeding in Poland is very limited. The causes of this situation are numerous, including a lack of appropriate technical guidelines and recommendations, experience, equipment park, consents from the project owner, availability of a good quality of RAP and other [11, 12]. Taking into account the properties of bituminous mixture with RAP, it must be ensured that it met the technical requirements, and the application of RAP would not deteriorate properties of the mixture. Certainly, these are the assumptions to ensure that the made bituminous layers will be characterised by the appropriate durability. The first factor which has a significant impact is the uniformity of the RAP [13], and in particular the contents and properties of asphalt binder. The larger the contents of RAP in the bituminous mixture, the more important is the factor. Another very important factor is the ageing process covering the bitumen layers, and the asphalt binder [14, 15]. Therefore, the application of reclaimed asphalt, i.e. the material after long-term and short-term ageing may raise concerns as to the characteristics of the bituminous mixture with addition of that material. A potentially increased rigidity and better resistance to permanent deformations may be expected [16]. On the other hand, those properties, where greater stiffness, and thus the resistance to cracking and fatigue resistance is not favourable, may be deteriorated. In order to verify these characteristics, it is necessary to conduct performance tests. If necessary, regenerative (rejuvenator) additives should be used, the mission of which is to improve the viscoelastic properties [17, 18]. The fatigue life is the primary characteristic determining the service life of the pavement [19]. A change of rheological properties of asphalt binder due to ageing can cause deterioration of the fatigue life of mixtures with RAP [20, 21]. There are also studies showing an opposite effect [22].

The results presented in this publication are part of the research work carried out within the framework of the “InnGA” project entitled: “Reclaimed asphalt pavement: Innovative technology of bituminous mixtures using material from reclaimed asphalt pavement”. The project is carried out by the scientific and industrial consortium composed of: The Road and Bridge Research Institute (leader), the Warsaw University of Technology and BUDIMEX S.A. The project is subsidised from the funds of the Operational Programme Innovative Economy under the “INNOTECH” programme in the IN-TECH programme path. The primary goal of the project is the development of bituminous mixtures with a possibly maximum content of reclaimed asphalt, while maintaining the corresponding properties of the mixture. Due to limitations of the volume of the text, the paper discusses designing of the selected bituminous mixtures (SMA11 and AC16W) with the content of reclaimed asphalt of up to 50% and the results of tests from verification of industrial production. Testing included basic tests according to the technical requirements of WT-2 [23] and the extended functional testing. The conducted tests and analyses helped to determine the usefulness of the developed bituminous mixtures for use in experimental sections and confirmed the possibility of using an increased amount of RAP up to 50% in mixtures intended for construction of national roads.

2. Design of bituminous mixtures with reclaimed asphalt

The research works carried out within the framework of the project included asphalt concrete for all courses, asphalt concrete type ACWMS and the SMA mixture. For the purpose of designing the mixtures of asphalt concrete (AC) and stone mastic asphalt (SMA), two materials were used with an established quality, recovered from the reclaimed asphalt pavements (RAP) using selective milling. RAP-AC from milling of the binder course was used for asphalt concrete mixes, while for the mixture

of stone mastic asphalt RAP-SMA from milling of the SMA wearing course was used. Properties of the recovered materials and their composition are shown in table 1.

Table 1. Properties of the materials recovered from the RAP.

Property		Unit	RAP-SMA (SMA<15 years)	RAP-AC (AC-W< 20 years)
Binder properties	Binder content	% (m/m)	5.9	4.3
	Penetration	0.1 mm	51	31
	Softening point acc. to ring and ball method	°C	55.4	62.4
	Fraass breaking point	°C	-16	-12
	Elastic recovery	%	75	43
Grading	Aggregate particles below 0.063 mm	% (m/m)	13.7	10.1
	Aggregate particles from 0.063 to 2 mm	% (m/m)	14.9	22.4
	Aggregate particles above 2 mm	% (m/m)	71.5	67.5
	Mineral mix density	[Mg/m ³]	2.703	2.635
Properties of aggregates	Percentage of crushed and broken surfaces in fine aggregate — flow indicator	seconds	33	28
	Percentage of crushed and broken surfaces in large aggregate	-	C _{100/0}	C _{100/0}

Although the materials recovered from the RAP have not been subjected to granulation, an increased content of the filler and fine aggregate was found in the particle size distribution of mineral materials. The conducted petrographic studies have shown that about 5% of the filler and fine aggregates comes from fragmentation of coarse-grain fractions. The sand fraction of the SMA mixture showed the presence of basalts and biotites from the stone mastic fraction, while the sand fraction of the AC mixture contained flakes of carbonate aggregate. The evaluation of properties of asphalt binders recovered from RAP showed that they were not stiffened as a result of ageing. The binder recovered from the SMA mixture after many years of trafficking in the road pavement shows elastic recovery at the level of 75%, which indicates that the polymer did not undergo degradation. The elastic recovery of the binder recovered from the asphalt concrete at the level of 43% proves partial presence of polymer-modified bitumens in that material, most probably originating from the wearing course.

In order to determine the maximum content of material recovered from the reclaimed asphalt pavement (RAP) in the new mixtures, five mixtures of asphalt concrete and stone mastic asphalt with a variable content of RAP were designed. The grading of the designed mixtures containing RAP is shown in figure 1, while figure 2 presents the breakdown of air voids in the tested mixtures. The samples were compacted in the Marshall hammer: asphalt concrete 2 x 75 blows, SMA 2 x 50 blows.

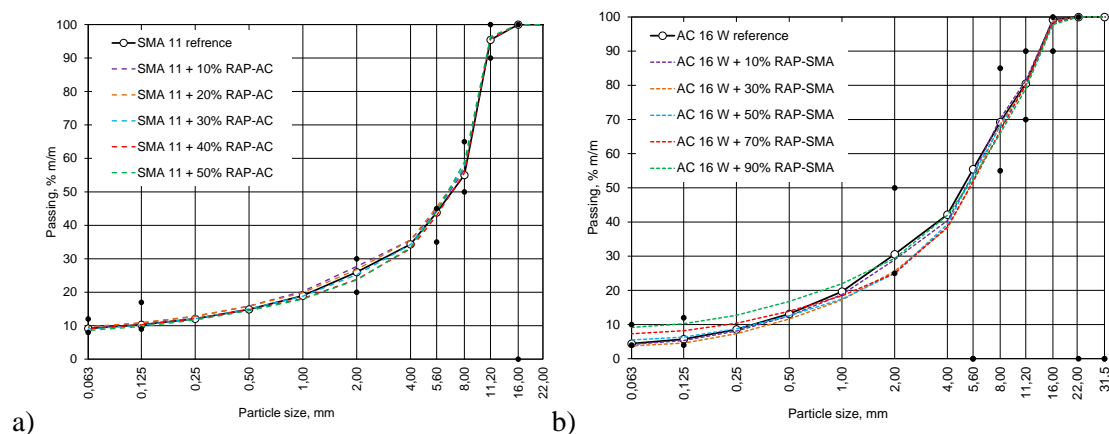


Figure 1. Grading curves of bituminous mixtures with various RAP content: a) SMA 11 + 0–50% RAP mixtures, b) AC 16 W + 0–90% RAP mixtures.

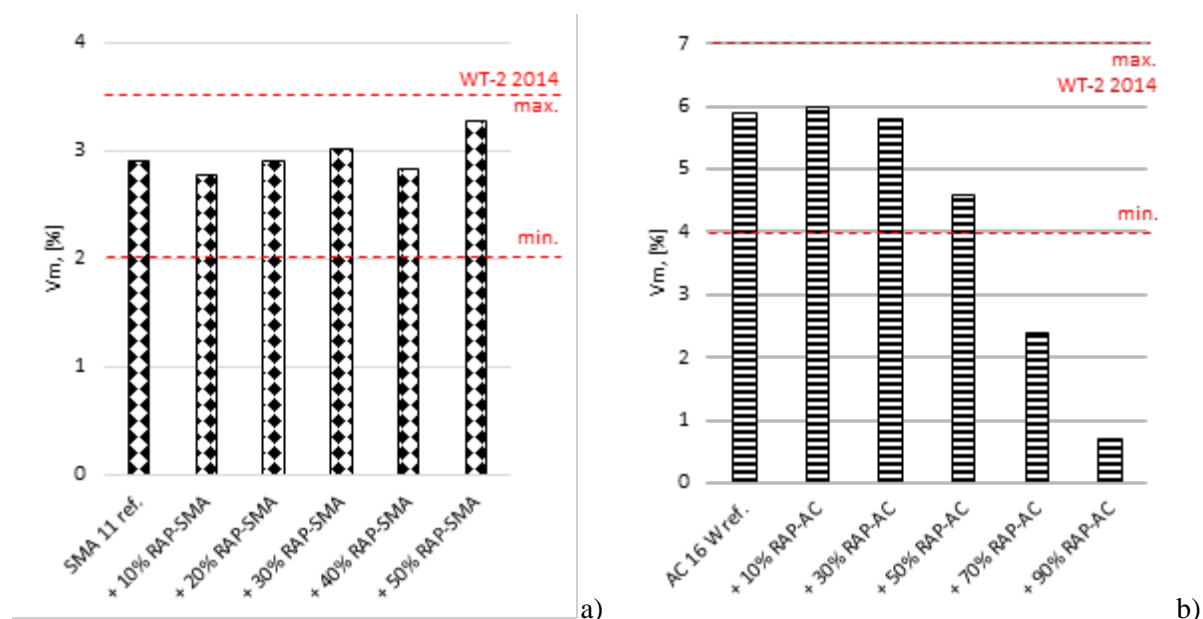


Figure 2. Comparison of air voids content of bituminous mixtures with various RAP content: a) SMA11 mixtures, b) AC16W mixtures.

The mixtures were designed so grading curves of mixtures containing RAP were possibly similar to the reference mixture. With the increase in the amount of RAP in the mixtures the amounts of filler and fine aggregates were gradually reduced. The necessity of their limitation was caused by the grading of the mineral mixture of the material recovered from the bituminous pavement containing relatively large amounts of fine fractions <2 mm. In the case of addition of RAP-AC to the AC16W at the level of 30%, it was necessary to completely eliminate the filler and crushed and not washed sand constituting 50% of the sand fraction in the reference mixture. In AC16W mixture containing 90% of RAP-AC, only one virgin aggregate in the form of 11/16 stone chippings was used. In the SMA11 mixture containing 50% of RAP-SMA, it was also necessary to reduce the amount of filler to the level of 1% and the amount of sands by half in relation to the reference mixture. In the case of mixtures containing 40% and 50% of the reclaimed asphalt admixture of 4/8 melaphyre rock was abandoned due to a high content of that fraction in the reclaimed asphalt pavement (the content of 4/8 fraction was about 42%).

The obtained results of air voids content in the AC16W mixture have shown that with the increase in the share of RAP-AC, voids content in the mixtures decreases. This phenomenon is associated with a high proportion of fine fractions in the mineral mixture of the reclaimed asphalt pavement (RAP) that fills the air voids in the mixture. Along with the increase of RAP, an increasing amount of fine fractions is added to the mixture; however, at the same time it is not possible to correct the grading using large aggregates. Figure 2 marks the range of the air voids content required according to WT-2 2014. It was found that the maximum share of the analysed reclaimed material (RAP) in the AC16W mixture allowing for meeting the requirements for the air voids content is 50% and with the favourable grading of RAP this amount could be potentially increased even up to 70%. The results of testing of SMA11 revealed that as opposed to the AC16W mixture, the use of RAP in the amount of 0–50% does not have to result in decrease in the air voids content. This is due to the fact that the material from milling of the wearing course SMA (RAP-SMA) used in this mixture is characterised by a much smaller (by about 18%) content of the fine fractions <2 mm in the mineral mixture in comparison to RAP-AC used in the AC16W mixture. All of the designed SMA mixtures with polymer-modified bitumen PMB 45/80-55 are characterised by similar contents of air voids within the limits of 2.8–3.3%.

When assessing the designed mixtures, it can be concluded that there is a possibility of designing bituminous mixtures with an increased content of RAP in the amount of 20% to 50% that meet the

current technical requirements. Grading of RAP is the main factor limiting the possibility of introducing greater amounts (above 50–70%) of the pavement to mixtures. Too much content of the filler fraction and fine aggregate significantly limits the possibility to design mixtures with the adequate air voids content, which in turn determines properties of the mixtures.

3. Production technology

The mixtures were produced in the asphalt mixing plant of the company Budimex S.A. near Jędrzejów (fig.3). The plant is one of the four plants in Poland equipped with the so-called black mixing drum for feeding hot reclaimed asphalt [21].



Figure 3. Asphalt plant with RAP drum on the top and view of RAP pile.

The reclaimed asphalt is subjected to the production process in a separate process line. A vibrating feeder conveys RAP to the elevator, which in turn transports the material to the black drum. There it is heated in temperature above 100°C (figure 4).



Figure 4. View of the inside of the black drum before and during production.

In the heating process the reclaimed asphalt is deprived of moisture and fragmented. Then RAP obtains the temperature within the range of 120–140°C. As a result of the carried out process, reclaimed asphalt changes its structure to become the material reminiscent of a loose bituminous



mixture (figure 5). Further the heated material is transported to the bunker, where after weighing the proper amount is fed directly to the mixer.

Figure 5. View of the reclaimed asphalt after passing the black drum.

The increased share of RAP in the mixtures due to the applied “hot method” did not require excessive heating of aggregates in order to balance the temperatures allowing for obtaining a bituminous mixture with a minimum production temperature resulting from the type of binder used. Figure 6 shows process temperatures at the production stage with the share of 30 and 50% of RAP, respectively.

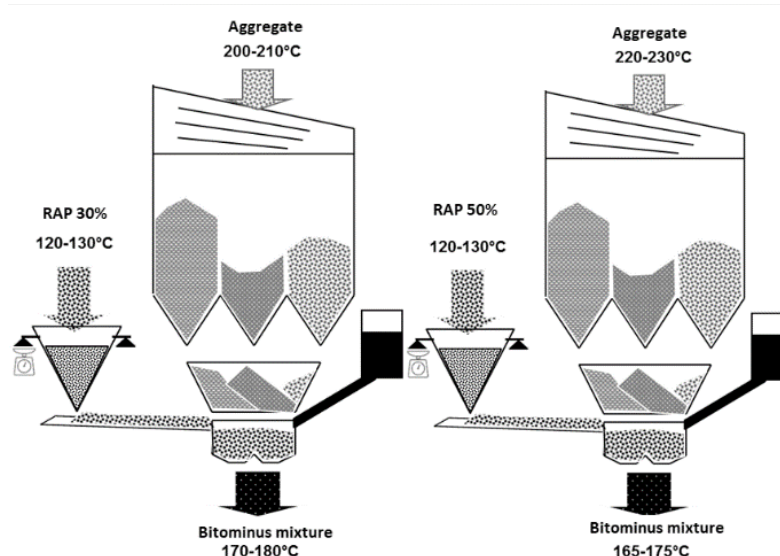


Figure 6. Process temperature in production of MMA with 30% and 50% share of RAP.

The production process used two types of reclaimed asphalt pavement: 45 RAP 0/16 — AC from the binder course and 45 RAP 0/11 — SMA from the wearing course. The batches of reclaimed asphalt were tested for homogeneity. The requirements of WT-2 2014 [23] were adopted as the criterion for assessment of homogeneity, whereas the current requirements do not allow for the use of recycled materials for the wearing course. Therefore, there are no requirements for mixtures for that course. Therefore, the requirements as for the binder course were assumed as the criterion for evaluation of the reclaimed asphalt pavement intended for wearing courses. The results of homogeneity showed compliance with the requirements. Table 2 presents the results of the homogeneity of the reclaimed asphalt pavement RAP-SMA.

Table 2. Evaluation of homogeneity 45 RAP 0/11 — SMA.

Property a_i	Unit	Span of results from n samples			Result range a_i	Requirements of WT-2 2014
Softening point of recovered binder;	[°C]	59.4	-	63.8	4.4	8.0
Contents of soluble binder (m/m);	[%]	5.8	-	6.2	0.4	1.0
Aggregate with grading of < 0.063 mm, (m/m);	[%]	13.4	-	15.0	1.6	10.0
Aggregate with grading from 0.063 to 2.0 mm, (m/m);	[%]	23.5	-	30.0	6.5	16.0
Aggregate with grading of > 2.0 mm, (m/m);	[%]	55.8	-	61.5	5.7	16.0

4. Verification of production of bituminous mixtures with reclaimed asphalt

The compositions of bituminous mixtures with admixture of RAP developed under laboratory conditions were used to produce trial mixes — production verification in the bituminous mixture mixing plant equipped with a parallel drum system. The aim of this work was to select the parameters and settings of the production process, to determine the working recipe and determine the properties of the mixtures in the range of basic and performance properties. The process of production of mixtures with reclaimed asphalt under laboratory conditions is in principle similar to heating and feeding of ingredients. However, it is obvious that both the production technology and the scale are different. It was therefore considered that it is important to confirm the properties of the mixtures with the increased content of RAP based on testing of mixtures taken from production trials. It was assumed that this will be the basis for the selection of the optimum compositions of mixtures to be used in experimental sections. The production trials and tests were conducted on five types of bituminous mixtures listed in table 3.

Table 3. Bituminous mixtures with reclaimed asphalt subjected to production tests.

Mixture	Reclaimed asphalt	Contents of RAP
AC22P 35/50 KR 3-7	45 RAP 0/16 AC	50%
AC16W PMB 25/55-60 KR 3-4	45 RAP 0/16 AC	50%
ACWMS16W PMB 25/55-60 KR 3-7	45 RAP 0/16 AC	50%
AC11S PMB 45/80-55 KR 3-4	45 RAP 0/11 SMA	15%
SMA11 PMB 45/80-55 KR 3-7	45 RAP 0/11 SMA	30%

The optimum setting of production parameters and the working recipe required several repetitions for each mixture. The task included production of 5 mixes from the SMA11 mixture, 1 mix of AC11S, 5 mixes of AC16W for binder course, 7 mixes of ACWMS16 (high modulus asphalt concrete) and 6 mixes of AC22P for base course. After each production trial the mixture was preliminarily evaluated in the field laboratory in order to determine compliance with the composition of the developed recipes, as well as in terms of compliance with the requirements of WT-2 2014. Mixtures with positive results were submitted in the laboratories of research units in order to perform further tests.

Table 4 summarises the results of testing of SMA11 mixture, which fulfilled the requirements of WT-2 in terms of basic properties and composition. The exception is the result of the wheel tracking test in a small apparatus, where the value of the proportional depth of the rut was exceeded. The results within the range of 8–8.9% were obtained for the permissible value of 7%. However, performance tests confirmed a good resistance of the mixture to permanent deformations using a large rutting tester. Technical requirements do not provide the required values for this method. However, previous technical documents that take this test method into account, provided the maximum value of

the rut at the level of 10% after 10,000 cycles. It is worth stressing the very good the result of resistance to low-temperature cracking. The cracking temperature at the level of -29°C is a typical result for mixtures without reclaimed asphalt with this type of polymer-modified binder. Despite the application of the reclaimed asphalt, a high resistance to water and frost was also obtained. Both features are particularly relevant for the durability of the wearing course.

Table 4. Basic and performance properties of the SMA 11 45/80-55 mixture.

Property	Unit	Laboratory		
		Road and Bridge Research Institute	Warsaw University of Technology	WT-2 2014 KR5-7
Mix bulk density	g/cm ³	2.379	2.357	-
Mix density	g/cm ³	2.437	2.429	-
Air voids	%, v/v	2.4	3.0	2.0–3.5
Resistance to water	ITSR	-	97	≥ 90
Resistance to permanent deformations, method B	WTS _{AIR}	0.09	0.08	≤ 0.1
	PRD _{AIR}	8.0	8.9	≤ 7.0
Rutting resistance, large apparatus, 30 thousand cycles	P	7.1	-	-
Stiffness (10 Hz, 10°C), MPa	E	7,853	-	-
Low-temperature cracking	T	-29.0	-	-
resistance (TSRST)	σ	3.8	-	-

Table 5. Basic and performance properties of the AC16W PMB 25/55-60 mixture.

Property	Unit	Laboratory		
		Road and Bridge Research Institute	Warsaw University of Technology	WT-2 2014 KR5-7
Mix bulk density	g/cm ³	2.417	2.390	-
Mix density	g/cm ³	2.518	2.509	-
Air voids	%, v/v	4.0	4.7	4.0–7.0
Resistance to water	ITSR	-	77	≥ 80
Resistance to permanent deformations, method B	WTS _{AIR}	0.18	0.14	≤ 0.15
	PRD _{AIR}	7.7	7.1	≤ 7.0
Rutting resistance, large apparatus, 30 thousand cycles	P	3.4	-	-
Fatigue life, 10°C, 10 Hz	ε ₆	133	-	-
Stiffness (10 Hz, 10°C), MPa	E	14 669	-	-
Low-temperature cracking	T	-20.4	-	-
resistance (TSRST)	σ	3.5	-	-

The AC16W 25/55-60 50%RAP mixture met the requirements in terms of basic properties and composition. The exception is the result of the wheel tracking test in a small apparatus, where the value of the proportional depth of the rut was exceeded. The results within the range of 7.1–7.7% were obtained for the permissible value of 7%. However, performance tests indicated a good resistance of the mixture to permanent deformations using a large rutting tester. The result of the proportional rut depth was 3.4%. The previous technical documents that take this test method into account, provided the maximum value of the rut at the level of 5% after 30,000 cycles. The technical requirements do not provide requirements for other performance characteristics. By evaluating the fatigue resistance, stiffness and resistance to low-temperature cracking, in general it may be concluded that the mixture does not demonstrate properties which could be expected from this type of mixture with polymer-

modified bitumen. This is related to the ratio between the “old” asphalt binder and the “fresh” asphalt binder in the bituminous mixture. In this case, the reclaimed asphalt is approximately 75% of the total asphalt in the mix. A small part of the fresh polymer-modified binder is not decisive in terms of resistance to low-temperature cracking or fatigue. The obtained values are at the characteristic level for mixtures with 20/30 or 35/50 unmodified asphalt binder.

5. Evaluation of the results and a selection for test sections

By using experience from the laboratory designing of bituminous mixtures with the reclaimed asphalt pavement (RAP), bituminous mixtures for the test sections were designed.

The main criterion for evaluation of the suitability of bituminous mixtures in the wearing course was the air voids content and resistance to water (ITSR), completed with resistance to low temperature (TSRST). The limit (maximum) content of RAP was assumed at the level of:

- 30% of RAP-SMA in SMA mixtures and the recommended use of polymer-modified bitumens,
- 15% RAP-SMA in AC mixtures and the recommended use of polymer-modified bitumens.

The main criteria for evaluation of the suitability of bituminous mixtures in the structural pavement courses, i.e. the binder course and the base course were the resistance to permanent deformations (rutting) and fatigue life in the case of mixtures intended for the traffic category KR5-7. The limit (maximum) content of RAP was assumed at the level of 50% of RAP-AC and the recommended use of polymer-modified bitumens. Table 6 presents the basic properties of the designed bituminous mixtures for the test sections. The purpose of the test sections is reevaluation of the produced mixtures and the constructed courses, which in turn has to allow for selection of solutions to be used in the section of the national road.

Table 6. Properties of the designed bituminous mixtures for the test sections.

Layer	Type of bituminous mixture and traffic category	Air voids %	Resistance to water (ITSR), %	Rutting resistance small apparatus	
				WTS _{AIR} mm/1000 cycles	PRD _{AIR} %
Wearing course	AC11S KR 3÷4	3.1	96	0.05	5.8
	SMA11 KR 5÷7	2.7	95	0.08	7.7
Binding course	AC16W KR 3÷4	5.0	99	0.14	6.2
	ACWMS16 KR 5÷7	3.4	90	0.10	5.0
Binder course	AC 22 KR 3÷7	5.5	86	0.10	5.4

6. Summary

The paper indicates that it is possible to design bituminous mixtures meeting the current national technical requirements (WT-2 2014) with the simultaneous exceeding of the maximum permissible content of RAP. Grading of RAP is the main factor limiting the possibility of introducing greater amounts (above 50–70%) of the pavement to mixtures. Too much content of the filler fraction and fine aggregate significantly limits the possibility to design mixtures with the adequate air voids content, which in turn determines properties of the mixtures. It was found that it is possible to use RAP in mixtures to be used in the wearing course. In the case of SMA, it is necessary to use the material recovered from the selective milling of the SMA wearing course. In the case of mixtures with continuous grading for the binder course and the base course, it is possible to use up to 50% of RAP from milling of the lower courses of bituminous pavements and the main limitation in increase of RAP content is its grading. Successful production trials were conducted in the mixing plant equipped with an additional drum for heating of reclaimed asphalt. The further stage of the project provided for construction of test sections and experimental sections, which will be the subject of subsequent publications.

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