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ASPHALT CONCRETE MIXTURES WITH ADDITION OF RECLAIMED ASPHALT PAVEMENTS

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Abstract

The effect of using reclaimed asphalt pavements (RAP) to asphalt concrete mixtures besides their utilization is to reduce the amount of the new bituminous binder and aggregate added to hot mix asphalt. This publication presents studies on asphalt mixtures with an increased up to 40 % amount of RAP additive with the simultaneous use of 2 types of added bitumen, i.e. 35/50 and PMB 25/55-60. The aim of the paper is the evaluation of the basic mixture properties in a wide range of operating temperatures, as a part of the AC testing at high temperatures, the resistance to rutting at 60 °C and indirect tensile strength at 40 °C. The assessment of properties at intermediate operating temperatures is based on indirect tensile tests, including: elastic stiffness modulus at 5 °C, 15 °C and 30 °C and static strength at 25 °C. The low temperature properties have been tested in water and frost resistance tests by indirect tensile strength ratio. The results of the study were subjected to the analysis of the statistical significance of differences, which showed an improvement in the resistance of AC with the addition of RAP to the formation of permanent deformations and an increase in the stiffness modulus as well as indirect tensile strength. There was no adverse effect of the RAP additive on asphalt mixtures resistance to water and frost action.

Keywords: reclaimed asphalt pavements (RAP), asphalt concrete (AC), indirect tensile strength (ITS), stiffness modulus, wheel tracking

1 Introduction

RAP is the most popular recycled material used in the production of asphalt mixtures around the world, and at the same time, the most obvious. In the American report prepared by Copeland [1] it was stated that the most economical use of RAP is in asphalt mixtures. The technical regulations of specific countries in the field of using this material differ quite significantly and depend primarily on the experience with this technology. As reported Swamy et al. [2], properties of the asphalt mixtures with RAP percentage up to 15 % differ negligibly. In the work of Noferini et al. [3] RAP can be incorporated into the investigated mixture at percentages up to 10 % with no significant effects on properties of bitumen. As a practical method for testing of bitumen binder with RAP content 20 % or higher Noferini et al. [3] proposed application of the DSR test with complex modulus, phase angle isochrones, the black space and the Cole-Cole diagram. According to work by Sontag et al. [4], addition of RAP to a mixture increased the resilient modulus and it is also affected by the source of RAP. At the same time in the report prepared by Lee et al. [5] it was stated that RAP addition generally increases the stiffness, reduces the rut depth and wheel tracking rate and reduces the fatigue life.

There is an upward trend in the frequency of using RAP in HMA as well as the proportion of this material in the composition of the mixture. Al-Qadi et al. [6] concluded that it is possible to design high-quality asphalt mixtures with up to 50 % RAP. Proper processing and fractionation of the RAP material at asphalt plant as well as binder-grade bumping (using more softer bitumen binder grade) is also recommended [6]. As Sorociak's research has shown [7], it is possible to produce a mixture containing almost 100 % RAP (with the addition of bitumen rejuvenating agent) that meets all functional requirements for new mixtures. To assess the effectiveness of the rejuvenating agents Sorociak recommends analysing the relationship of AC stiffness as a function of phase angle. Hagos et al. [8] also confirmed that 100 % RAP mixtures with an addition of an innovative rejuvenator can be applied as a base and binder layer in pavements of all traffic classes including heavy duty.
The main problems of mixtures with RAP addition are: material quality and heterogeneity, bitumen ageing causing a drop in the mixture resistance to cracking, lack of additional installation for RAP dosing and lack of experience [1].
The purpose of this publication is the evaluation of the basic properties of the asphalt concrete mixture with an increased up to 40 % amount of RAP additive (with the simultaneous use of 2 types of added bitumen, i.e. 35/50 and PMB 25/55-60) in a wide range of operating temperatures.

2 Materials and methods

A mixture of asphalt concrete AC 16 for the bonding course with paving bitumen 35/50 was used for the test as reference mix. The results obtained on this mix were compared with the results of mixtures with the addition of 40 % RAP, differing in the type of bitumen used, i.e. 35/50 and PMB 25/55-60.
Testing mixtures were designed in such a way that the total content of bitumen binders and the grading curves of all mixes were constant. Details concerning the test mixtures composition and gradation is given in Table 1 and in Table 2, respectively.

Table 1 AC composition

O.N.	Components	Participation in AC [%] for the HMA			
		(35/50)	PMB	RAP (35/50)	RAP (PMB)
1	Limestone filler	4.8	4.8	1.9	1.9
2	Dolomite 0/4	28.7	28.7	19.4	19.4
3	Dolomite 2/8	33.4	33.4	21.3	21.3
4	Dolomite 8/11	14.3	14.3	9.7	9.7
5	Dolomite 8/16	14.3	14.3	5.8	5.8
6	RAP	-	-	38.8	38.8
7	Fresh bitumen	4.5	4.5	3.1	3.1

Table 2 AC gradation

Sieve size [mm]	Grading curve [%]		
	RAP	**Reference mixtures**	**Mixtures with RAP addition**
22.4	100	100	100
16.0	94.9	98.6	96.8
11.2	85.5	84.6	85.6
8.0	68.2	70.8	68.9
5.6	55.8	57.7	51.4
2.0	35.6	28.0	27.6
0.5	21.1	13.2	14.3
0.125	11.8	8.4	8.3
0.063	10.3	6.9	6.9
Bitumen amount	3.5	4.5	4.5

For each of the above 4 mixtures, the following samples were prepared:

- Loose mixture for maximum density test in pycnometer according to EN 12697-5;
- Cylindrical with a diameter of 101.6 mm and a height of approx. 63.5 mm, compacted with a Marshall hammer at 2 x 75 blows and 2 x 35 blows acc. to EN 12697-30;
- Cylindrical with a diameter and a height of 100 mm, compacted with gyratory press up to 200 rotation acc. to EN 12697-31;
- Plates with dimensions of 305x305x60 mm, compacted in a roller compactor according to EN 12697-33.

The program of the AC study is given in Table 3.

Table 3 Program of AC tests

O.N.	Tested property	Testing standard	Number of samples for the AC type			
			REF (35/50)	(PMB 25/55-60)	RAP (35/50)	RAP (PMB 25/55-60)
1	Maximum density	EN-12697-5	3	3	3	3
2	Bulk density	EN-12697-6	8	8	5	5
3	Air voids	EN-12697-8	8	8	5	5
4	Wheel tracking at +60°C	EN-12697-22	1	2	1	2
5	Stiffness modulus at 3 temp.: +5°C, +15°C and +30°C	EN-12697-26	5	5	5	5
6	ITS, samples 2 x 75 blows (and 200 gyration), tested at +40°C	EN-12697-23	4 (4)	4 (4)	5 (4)	5 (4)
7	ITS, samples 2 x 35 blows on wet and (dry) condition at +25°C	EN-12697-23	5 (5)	5 (5)	5 (5)	5 (5)

3 Results

The results of the individual tests are summarized in tables and figures, for tests where the number of samples in the series was at least 4, statistical analyses were performed to verify the hypothesis that the results for RAP mixtures differ significantly from the results of the reference mix. Statistical analyses were conducted with the use of computer program Statgraphics Plus v. 5.1. [9] according to the procedure given in [10]. Tests were performed to find out if there was any statistically significant difference between the averages of the variable at a given confidence level equal 0.95. ANOVA Table was used for this purpose. To determine which interlayer systems differ significantly from one another, the analysis of multiply range tests with application of LSD (least square differences) option was used.

3.1 Physical parameters

Before executing performance tests, the maximum density and bulk density of HMA samples were tested, then content of the air voids in compacted samples were calculated, examples of obtained results are included in Table 4.

Table 4 Results of air voids content in Marshall samples [%]

Samples compacted 2 x 35 blows							
Mixture type	**count**	**average**	**std. dev.**	**coef of var.**	**minimum**	**maximum**	**range**
REF (35/50)	10	7.4	0.26	3.5	7.0	7.8	0.8
RAP (35/50)	10	8.7	0.27	3.1	8.3	9.1	0.8
(PMB 25/55-60)	10	7.7	0.30	3.9	7.3	8.2	0.9
RAP (PMB 25/55-60)	9	7.8	0.40	5.2	7.1	8.5	1.4
Samples compacted 2 x 75 blows							
REF (35/50)	8	6.4	0.76	11.8	5.2	7.2	2.0
RAP (35/50)	8	6.4	0.40	6.2	5.9	6.8	0.9
(PMB 25/55-60)	5	6.2	0.38	6.1	5.8	6.8	1.0
RAP (PMB 25/55-60)	5	5.6	0.30	5.4	5.1	5.8	0.7

3.2 Wheel tracking

For wheel tracking tests each mixture was tested at 60°C using the method of small apparatus acc. to PN-EN 12697-22. The test results covering proportional rut depth (PRD) and wheel tracking speed (WTS) are summarized in Table 5.

Table 5 Wheel tracking results for AC

Mixture type	**Rut depth**		**WTS_{AIR}**
	FRD [mm]	**PRD_{AIR} [%]**	**[mm/1000 cycles]**
REF (35/50)	3.50	5.8	0.078
RAP (35/50)	2.10	3.5	0.052
(PMB 25/55-60)	1.95	3.3	0.040
RAP (PMB 25/55-60)	1.80	3.0	0.038

3.3 Stiffness modulus

The tests were performed on cylindrical Marshall samples, compacted 2 × 75 blows with indirect tensile method, at 3 temperatures: + 5°C, + 15°C and + 30°C. On each sample, tests were performed on 2 mutually perpendicular diameters using 5 pulses of load, results are given in Table 6, while their statistical tests in Table 7.

Table 6 Results of AC stiffness modulus (E) [MPa]

Mixture type	count	average	std. dev.	coef of var.	minimum	maximum	range
Temperature of test +5°C – E(5)							
REF (35/50)	10	11959	1107	9.3	10502	13400	2898
RAP (35/50)	10	13660	793	5.8	12453	14985	2532
(PMB 25/55-60)	6	13422	569	4.2	12735	14012	1277
RAP (PMB 25/55-60)	6	16355	906	5.5	15246	19966	2720
Temperature of test +15°C – E(15)							
REF (35/50)	10	7065	427	6.0	6229	7568	1339
RAP (35/50)	10	9093	741	8.1	7816	10101	2285
(PMB 25/55-60)	10	7944	316	4.0	7499	8382	883
RAP (PMB 25/55-60)	8	10348	589	5.7	9522	11131	1609
Temperature of test +30°C – E(30)							
REF (35/50)	10	2415	163	6.8	2167	2688	521
RAP (35/50)	10	3523	166	4.7	3192	3830	638
(PMB 25/55-60)	10	2542	97	3.8	2432	2711	279
RAP (PMB 25/55-60)	10	3955	295	7.5	3607	4558	951

Table 7 Results of significance tests for AC stiffness modulus

Contrast	+5°C		+15°C		+30°C	
	difference	+/- limits	difference	+/- limits	difference	+/- limits
REF (35/50) - RAP (35/50)	1701*	820	2029*	491	1108*	176
REF (35/50) - (PMB 25/55-60)	1463*	946	879*	491	126	176
REF (35/50) - RAP (PMB 25/55-60)	4396*	946	3284*	520	1539*	176
RAP (35/50) - (PMB 25/55-60)	238	946	1149*	491	982*	176
RAP (35/50) - RAP (PMB 25/55-60)	2694*	946	1254*	520	431*	176
(PMB 25/55-60) - RAP (PMB 25/55-60)	2933*	1058	2404*	520	1413*	176

* denotes a statistically significant difference

3.4 Indirect tensile strength

The tests were performed on cylindrical Marshall samples, compacted 2×35 blows and 2×75 blows respectively. The basic temperature of the study was 25 °C, whereas samples compacted 2×75 blows were also tested at the temperature of 40 °C. In the case of 2×35 blow samples, 2 types of conditioning were used, i.e. dry and wet conditions with one freezing cycle, according to Polish Technical Requirement WT-2 [11] and next indirect tensile strength ratio (ITSR) was calculated according to equation (1).

$$ITSR = \frac{ITS_{wet}}{ITS_{dry}} \cdot 100\% \tag{1}$$

where: $ITS_{(wet/dry)}$ – indirect tensile strength for (wet/dry) series of samples

Results of ITS tests at the temperature 25 °C as well as ITSR results are given in Table 8, while results of ITS tests at the temperature 40 °C are presented in Table 9. Statistical tests in for ITS results are given in Table 10.

Table 8 Results of indirect tensile strength (ITS) [kPa] at the temperature of 25 °C

Samples compacted 2 x 35 blows, wet conditions								**ITSR [%]**
Mixture type	**count**	**average**	**std. dev.**	**coef of var.**	**minimum**	**maximum**	**range**	
REF (35/50)	5	960	55	5.7	864	996	132	90.0
RAP (35/50)	5	985	54	5.4	907	1054	147	92.2
(PMB 25/55-60)	5	1046	84	8.1	961	1171	210	91.0
RAP (PMB 25/55-60)	4	1041	58	5.6	961	1089	128	89.1
Samples compacted 2 x 35 blows, dry conditions								
REF (35/50)	5	1067	108	10.1	980	1247	267	
RAP (35/50)	5	1068	92	8.6	962	1168	206	
(PMB 25/55-60)	5	1149	70	6.1	1074	1239	165	
RAP (PMB 25/55-60)	4	1168	60	5.2	1081	1217	136	

Table 9 Results of indirect tensile strength (ITS) [kPa]

Samples compacted 2 x 75 blows, dry conditions, +40 °C							
Mixture type	**count**	**average**	**std. dev.**	**coef of var.**	**minimum**	**maximum**	**range**
REF (35/50)	4	481	37	7.6	443	523	80
RAP (35/50)	4	618	49	8.0	564	670	106
(PMB 25/55-60)	4	583	29	5.0	544	614	70
RAP (PMB 25/55-60)	4	747	65	8.8	690	827	137
Samples compacted up to 200 gyrations, dry conditions, +40 °C							
REF (35/50)	4	564	25	4.4	541	594	53
RAP (35/50)	4	761	30	3.9	717	779	62
(PMB 25/55-60)	4	820	38	4.6	785	873	88
RAP (PMB 25/55-60)	4	850	43	5.0	805	907	102

Table 10 Results of significance tests for ITS

Contrast	2 x 35, wet, +25 °C		2 x 35, dry, +25 °C		2 x 75, dry, +40 °C		200 gyr., dry, +40 °C	
	difference	+/- limits	difference	+/- limits	difference	+/- limits	difference	+/- limits
REF (35/50) – RAP (35/50)	26	87	1	116	137*	60	197*	60
REF (35/50) – (PMB 25/55-60)	86	87	82	116	101*	60	255*	60
REF (35/50) – RAP (PMB 25/55-60)	81	92	101	123	265*	60	285*	60
RAP (35/50) – (PMB 25/55-60)	60	87	81	116	35	60	58	60
RAP (35/50) – RAP (PMB 25/55-60)	56	92	100	123	129*	60	88*	60
(PMB 25/55-60) – RAP (PMB 25/55-60)	5	92	19	123	164*	60	30	60

* denotes a statistically significant difference

4 Discussion

Summarizing the results of the physical characteristics tests, it was found that the designed mixtures, for each series of samples compacted with the same energy, had similar air voids. The above condition allows to compare the strength properties of mixtures with the negligible influence of its physical characteristics.

In the case of the elastic stiffness modulus, the statistical tests showed that the mixtures with RAP addition were significantly stiffer than the reference mixture, regardless of the type of the added binder (35/50 or PMB 25/55-60) and the temperature of the test. Moreover, the RAP mixtures have proven to be less thermal sensitive than the reference mixtures, which is a beneficial phenomenon. The stiffness modulus ratio, calculated as a stiffness modulus at the temperature of 5°C divided by the stiffness modulus at the temperature of 30°C, for samples with the addition of RAP is 3.9 and 4.1, respectively (for bitumen 35/50 and PMB), while for the reference mixture it is 5.0 and 5.3, respectively. The above observation can be explained by the lower thermal sensitivity of the binder contained in the used RAP.

Wheel tracking test shows better performance for RAP mixtures, especially in the case of paving bitumen application, where rutting parameters were reduced by about 33 % (PRD) to 40 % (WTS), while in the case of PMB mixtures effect of RAP addition caused the reduction of rutting parameters by less than 10 %. Studies have also confirmed the beneficial effect of the use of polymer modified bitumen, the rutting parameters have been reduced by almost half, which is in line with most studies.

All of tested mixtures obtained a similar assessment in terms of resistance to water and frost action, calculated ITSR values are within the limits of 89.1 - 92.2 %, i.e. significantly above the value required by WT-2 [11] (minimum 80 %).

ITS results at the temperature of 25°C for RAP mixtures are not significantly different from reference mixtures, regardless of sample seasoning conditions (wet or dry).

In accordance with works [12, 13] the ITS test at elevated temperature can be used to assess the resistance of asphalt mixtures to permanent deformations. This was confirmed by the results of ITS tests at a temperature of 40°C, both on samples compacted in the gyratory press and in the Marshall hammer. PMB mixtures give significantly higher tensile strength than paving bitumen mixtures and at the same time, RAP mixtures obtained higher ITS results than reference ones. In addition, the strength of gyratory samples was found to be higher than Marshall samples, which can be explained by the lower air voids content in gyratory samples (higher compaction energy).

5 Conclusions

The presented test results indicate the potential possibility of increased up to 40 % addition reclaimed asphalt pavement to asphalt concrete mixture. The asphalt concretes for binding course (AC 16 W 35/50 and AC 16 W PMB 25/55-60) with 40 % of RAP addition meet all the requirements given in Polish Technical Requirements WT-2 [11], e.g.: content of the air voids, the proportional rut depth, the wheel tracking speed, and the resistance to water and frost action as the indirect tensile strength ratio. The RAP mixtures, despite the same content of the air voids in samples, obtained much higher stiffness modules (regardless of the test temperature) and, moreover, they are characterized by lower thermal sensitivity than reference mixtures. In terms of the resistance of the mixture to the formation of permanent deformation, the addition of RAP proved to be an effective solution, especially in the case of the paving bitumen mixtures. The above conclusion from the rut research was also confirmed by the results of indirect tensile strength (ITS) tests at a temperature of 40°C in contrast to the results of the ITS study at 25°C (no differences between the tested mixtures).
Finally, the results show, that mixture with an increased up to 40 % amount of RAP improves the AC properties in the elevated and the intermediate temperatures, not affecting the water and frost action. Fatigue tests and low-temperature fractures are necessary for a full assessment of these mixtures.

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