Asphalt mixture performance and testing

Full (100%) use of RAP in new HMA - possibilities and innovative evaluation process of rejuvenation effectiveness

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Abstract

Nowadays, use of RAP (reclaimed asphalt pavement) in new HMA (hot mix asphalt) is the most important kind of its use. According to current knowledge the content of RAP in HMA depends on the properties of asphalt binder in RAP. The paper contains laboratory tests results of efficiency of RAP rejuvenation with chosen chemical substances focused on required properties of HMA. The results show that restoration of properties of aged asphalt binder may lead to full (100%) use of RAP in new HMA. The paper also contains proposal of rejuvenation effectiveness based on stiffness results analyzes.

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1. INTRODUCTION

Nowadays more and more civilisation concerns focus on sustainable development. It means that there is growing need for preservation of natural resources, especially those non-renewable. These challenges apply to almost every fields of human life, with emphasis on industrial fields. Many actions are taken to increase recycling of goods and to limit anthropogenic influence on environment and these actions are also visible in road engineering. The steps taken in road engineering focus on limiting production of greenhouse gases (mainly CO_2) and increasing use of waste materials. As the limitation of waste materials disposal proceeds the reclaimed asphalt pavement (RAP), obtained from dismantled asphalt layers becomes subject of many researches and a chance for significant improvement in terms of recycling and economy.

The need for recycling RAP is becoming an important issue of highly civilised countries. Already built infrastructure requires renovation, which is based on change of top asphalt layers. During this process the same amount of RAP is produced as the HMA is used. It means that in areas, where no new roads are build recycling of material obtained from old asphalt pavement is especially significant.

Currently, depending on country, there are different limitations in terms of RAP use. In some countries it became a common practise to use more than 50% of RAP in base course layer, while in others (like Poland) it is no allowed to exceed 30% (according to Polish technical document WT-2 [1]). In case of Poland the problem lies in RAP management. Improper RAP dismantling leads to lack of trust in hot mix asphalt (HMA) containing high amount of RAP (high RAP HMA). Nevertheless, the need for environmental preservation ensures continuation or researches dealing with higher content RAP use.

2. THEORETICAL BACKGROUND

Intensive works on RAP recycling are in progress to enable sufficient recycling of dismantled road pavement. Many studies have been carried out in 21st century and many are still in progress. They all dealt with topic of safe high RAP HMA production. The studies try to show that there is technical possibility of use of HMA containing higher amount of RAP than it is allowed by present road administrators.

Despite limitations among road administrators in terms of RAP use, industry is getting prepared for change. There have already been invented machines being able to heat mix containing nearly 100% of RAP for its use as normal asphalt layer. These inventions come from all around the world. Zaumanis [2] presented solutions for heating RAP to produce high RAP HMA. The solutions cover technologies of different RAP heating methods like:

- heating by hot gasses introduced in satellite drum (HERA System),
- heating by flame in separate combustion chamber (Bagatela),
- heating in drum equipped in elements protecting RAP against direct contact with flame (Benninghoven),
- heating in parallel drum with 4 points of RAP entry (for different sizes of RAP) (HyRAP),
- heating by conductive system during slow movement in auger (RapSaver),
- heating by microwaves (Cyclean),
- heating directly by flame with use of air filters and rejuvenators (All-RAP Plant),
- heating in separate combustion chamber with counter flow of RAP (Ammann RAH 100 Plant),
- heating by 7 burners located in heating chamber perpendicularly to rotating RAP drum dryer (Alex Sin Manufacturing Plant)
- heating burner placed in a tube installed inside of the drum (Rapmaster™),
- heating from separate hot air generator in triangle profile generator (RAPTech Plant).

Most of these inventions are constructed to protect RAP against high temperature. Asphalt binder should not exceed temperature of 220°C – its ignition temperature. Burnt binder is much more brittle, which may result in pavement cracks. Moreover, oxidation processes occur not only during burning of asphalt binder but also during its normal existence. The higher temperatures are, the faster oxidation occurs, leading to increase in HMA stiffness ([3], [4]) and low temperatures brittleness ([5], [6]) Consequently it also makes HMA prone to fatigue cracking ([5], [7], [8]). Meanwhile, aging process of bitumen seems to have a positive effect on rutting resistance because of aged binder excessive stiffness ([9], [10]). Surprisingly, there have been no negative effect of high RAP HMA on water susceptibility, which means that mixes were similarly or less water susceptible ([11], [12]).

Even if asphalt binder is well protected against high temperatures it undergoes above explained changes (ageing process). These changes are present in asphalt binder due to chemical reactions (oxidation) of some of its components, volatilization and physical hardening. To understand how these changes work it is essential to know how asphalt binder is built. Simplifying, asphalt binder consists of different chemical groups. Different researches have proposed different chemical asphalt binder composition. For the purpose of this study division on 3 fractions seems to be reasonable. These fractions are oils, resins and asphaltenes. Oils are the lightest, part of them is the least polar (saturates) and almost resistance to chemical ageing (oxidation). Oils usually have fluid state of matter. Oils also act as filling of the spaces between heavier and more polar asphaltenes. During oxidation part of oils (aromatics) may turn into resins and part of resins turn into asphaltenes. In general, the colloidal structure of asphalt binder afer oxidation reactions is disturbed and there are too many heavy and solid particles (asphaltenes), additionally possessing polar characteristics. This leads further to cluster formation and increase in viscosity and stiffness of binder. Loss of oils because of volatilisation makes this effect even more visible. ([13], [14])

In conclusion, the asphalt binder, which is present in RAP, behaves differently than virgin binder. This is the reason why in many cases of high RAP use, special agent (rejuvenator) is required. Principle of work of most of rejuvenators was shown by Brownridge [15] (Figure 1). After changes in binder's chemical structure, rejuvenator ensures proper colloidal structure, enabling processing of RAP and proper HMA characteristics in pavement construction.

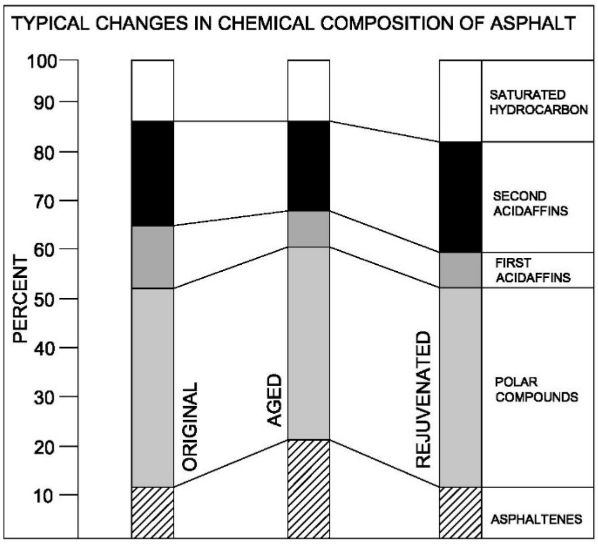

Figure 1. Changes in binder's chemical fractions during binder's ageing and rejuvenation [15]

The remaining problem of high RAP HMA production is proper RAP management and dismantling of old pavement and during the time of RAP storage. Asphalt layers, even within one pavement construction, have different properties at the very beginning of road exploitation. Moreover, due to different exposure to sunlight oxygen and other external factors the layer undergo ageing processes with different intensity. This is reason why also proper management may have great influence on any attempt of high RAP HMA production and is vital to make further steps in terms of RAP utilisation.

3. OBJECTIVES

The aim of this study is to confirm possibility of almost full (over 99% RAP and up to 1% rejuvenator) RAP recycling. This possibility would positively affect the whole process of old asphalt pavement reconstruction, limiting both use of non-renewable resources and carbon footprint.

The study also investigates the influence of different rejuvenators on new HMA, checking if change of curing agent may have a significant on asphalt mix characteristics.

4. RESEARCH PROGRAMME

4.1. RAP properties

First step of research programme was choice of RAP. On Polish building site milling of asphalt layers never occurs separately. For the sake of this study one of the ongoing contracts accepted request for milling all 3 asphalt layers (wearing course, binder course and base course) separately. It allowed to obtain RAP from one asphalt mix exploited in pavement for 11 years. The RAP was afterwards stored in closed room, protected from sunlight. Before milling core had been drilled to check air void content of all layers' HMA and their thickness. For further testes only base course RAP was used. Necessary information obtained from core of base course with reference to standard used are presented in Table 1 and Table 2. These information allowed to make an attempt to produce in laboratory AC 22 (for base course) for heavy traffic (Polish traffic category KR 5) according to polish requirements for national roads (WT-2[1]).

Table 1. Asphalt base course layer properties

Property	Standard	Unit	Result
Binder content	PN-EN 12697-1 [16]	%	3,5
Air void content	PN-EN 12697-8 [18]	% v/v	6,0
Particle size distribution	PN-EN 12697-2 [17]	-	(Table 2)
Thickness	-	cm	7,5

Table 2. Asphalt base course layer particle size distribution

Sieve size [mm]	Sieve fractions [%]	Cumulative undersize [%]
31,5	0	100
22,4	3	97
16	9	88
11,2	17	71
8	20	51
5,6	13	38
4	7	31
2	9	22
1	5	17
0,5	4	13
0,25	4	9
0,125	2	7
0,063	1	6,4
0	6,4	

4.2. 100% RAP HMA

AC 22 mix for heavy traffic should be resistant to rutting, insensitive to water and should possess adequate air void content. Apart from those three tests recommended in WT-2 [1], the mix was examined in terms of stiffness and fatigue resistance. It was essential to set required from the mix properties for the sake of high RAP HMA evaluation. In Table 3 there are presented requirements determined on the basis of current and past Polish technical documents for base course mixes. Fatigue test requirement was taken from available requirement for high modulus mixes but the testing method described in standard was modified. The test was carried out only by one strain value (130 µm) and it was expected that mean result should be at least 1 000 000 cycles before sample's stiffness drops by 50%. Rutting test was made in accordance with standard PN-EN 12697-22 [20] (method B, small apparatus in air), water sensitivity in accordance with standard PN-EN 12697-12[19], stiffness in accordance with standard PN-EN 12697-26 [21], and fatigue test was done as described above with modified method. Stiffness and fatigue tests were carried out using 4 point bending beam method (4PB-PR).

Table 3. Requirements established for high RAP HMA mix for heavy traffic base courses

Property	Unit	Requirement	
		min	max
Water sensitivity (ITSR)	%	70	-
Proportional rut depth PRD_{AIR}	%	-	7,0
Stiffness	MPa	11 000	17 000
Fatigue life (cycles of 130 µm strain)	cycles	1 000 000	-
Air void content	% v/v	4,0	7,0

First attempt of high RAP HMA production based on heating RAP and compacting samples in 150 °C according to bulk gravity (density) obtained from samples after 75 blows per side in Marshall compactor. The samples were examined in terms of properties listed in Table 3. Result of tests carried out on headed and compacted 100% RAP mix without any additives are presented in Table 4.

Table 4. 100% RAP HMA results

Property	Unit	100% RAP mix results
Water sensitivity (ITSR)	%	85
Proportional rut depth PRD_{AIR}	%	4,1
Stiffness	MPa	18 463
Fatigue life (cycles of 130 µm strain)	Cycles	42 084
Air void content	% v/v	8,5

Comparing results of 100% RAP mix with expected parameters it is visible that the mix fulfil requirements in terms of water sensitivity and proportional rut depth. Other parameters were outside of desired range. Such situation was expected as the literature review showed that rutting resistance is improving as the stiffness increases (results showed too high stiffness). Fatigue resistance was too low and air void content was too high due to poor workability with aged bitumen.

4.3. RAP rejuvenation

To restore properties of the 100% RAP HMA four rejuvenators were chosen. Their task was to bring values of stiffness, fatigue life and air void content to desired level. The rejuvenators differed from each other to obtain possibly most information:

- D1 – popular agent based on re-refined industry oils,
- D2 – popular agent – resin of organic origin,
- D3 – soft bitumen of viscosity V6000,
- D4 – experimental agent of animal fat origin.

In temperature 20°C three of testes rejuvenators were fluids (D1, D2, D3) and one was solid (D4). However, in temperature 60°C (temperature of rutting test) all of them were fluids.

100% RAP mix was enriched with rejuvenators. All of rejuvenators were tested with dosage of 0,4% of mass of the whole RAP. The mix was produced in 150°C, the rejuvenator was introduced during mixing of the rap. The results of these mixes with rejuvenator are presented in Table 5.

Table 5. Enriched with rejuvenators 100% RAP HMA results

Property	Unit	D1 0,4%	D2 0,4%	D3 0,4%	D4 0,4%
Water sensitivity (ITSR)	%	97	96	99	93
Proportional rut depth PRD_{AIR}	%	5,9	4,7	8,1	9,6
Stiffness	MPa	11 697	14 076	14 306	12 688
Fatigue life (cycles of 130 µm strain)	cycles	1 429 167	2 349 500	361 500	728 833
Air void content	% v/v	6,3	6,8	9,1	7,1

Data from Table 5 clearly show the way how rejuvenators affected high RAP HMA properties. All of mixes had higher ITSR (were less water sensitive), higher proportional rut depth (worse rutting resistance), lower stiffness and better fatigue resistance. In terms of air void content, the results depended on type of rejuvenator used.

Different RAP reaction to rejuvenator D3 in terms of air void content could be explained by the results presented in paper [24]. Before doing full asphalt mix tests, air void content and Marshall stability and flow tests were carried out on the same homogenous RAP as in this paper with different dosages of the same rejuvenators. On the basis of air void content test it was observed that rejuvenator D3 did not act it as was supposed to act. It could be caused by the fact that after mixing time and before compaction, the mix lost some of the applied rejuvenator. In comparison to other rejuvenators, D3 rejuvenator seemed not to interact with the asphalt binder of the RAP. In all containers with the mix there were rejuvenator D3 leftovers, which was more significant for smaller test samples (as in air void content and Marshall tests).

4.4. Rejuvenators evaluation

During stiffness and fatigue tests it was investigated if change of phase angle depending on frequency of stiffness test has any correlation with rejuvenators' efficiency. The stiffness test was carried out in 10°C using 21 steps (3 times repeated 7 testing frequencies) (Table 6). For the purpose of stiffness only frequency 10 Hz was taken into account. For the sake of rejuvenator efficiency analysis frequencies 1 Hz, 2 Hz, 3 Hz, 5 Hz, 8 Hz and 10 Hz were taken into account.

Table 6. Stiffness testing procedure

Step	Frequency	Strain	Cycles
1	0,5	50	5
2	1	50	10
3	2	50	20
4	3	50	30
5	5	50	50
6	8	50	80
7	10	50	100
8	0,5	50	5
9	1	50	10
10	2	50	20
11	3	50	30
12	5	50	50
13	8	50	80
14	10	50	100
15	0,5	50	5
16	1	50	10
17	2	50	20
18	3	50	30
19	5	50	50
20	8	50	80
21	10	50	100

On the basis of obtained results for different rejuvenators the analysis was made similarly to Johannsen [22] and Jimenes del Barco-Carrion [23], but instead of asphalt binder, the HMA was analysed. In general the publications imply that if the phase angle is greater without loss of stiffness modulus, the mix is more fatigue and rutting resistant. The results of the analysis are shown in Figure 2.

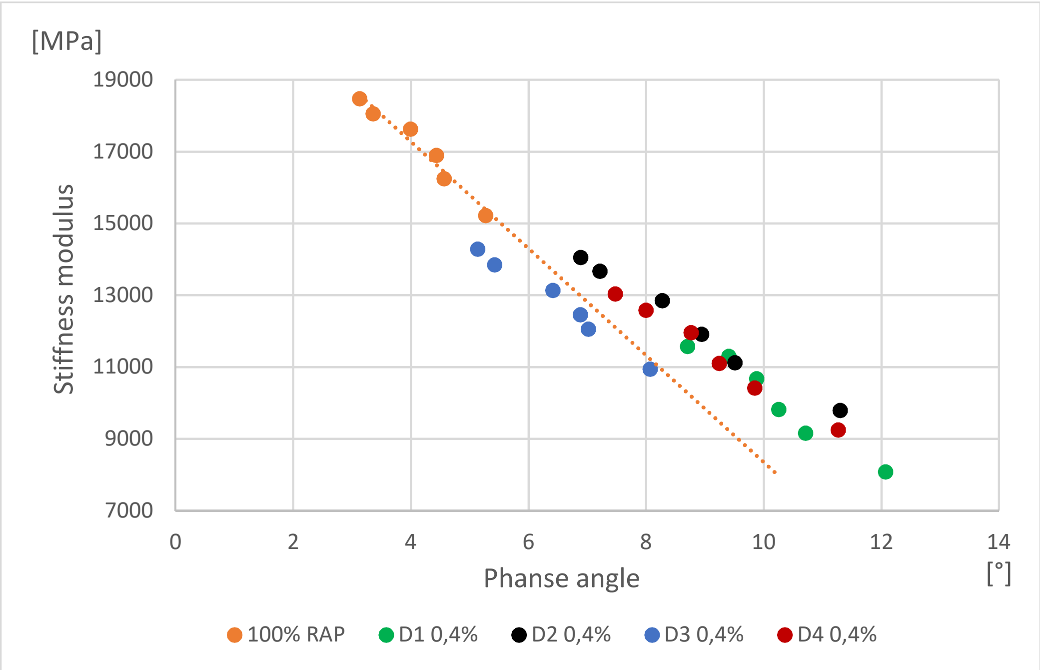

Figure 2. Black diagram obtained for HMA from stiffness test

Comparing results from black diagram and from all other laboratory tests is can be noticed, that the mix with rejuvenator D3 (the worst in terms of fatigue resistance) is placed below the artificial line created by extrapolation of trendline of non-rejuvenated mix. According to Johannsen [14] it probable means that the rejuvenator was not compatible with the RAP's binder. Surprisingly, rejuvenator D4 is placed above the trendline which should be further investigated.

5. CONCLUSION AND DISCUSSION

The investigation presented in the paper proved that there is possibility to produce hot mix asphalt containing over 99% of RAP under condition of proper RAP management and use of special additives. Such a mix was indistinguishable from traditional mix without RAP. Visually 100% RAP mix did not differ from traditional one, and with use of proper rejuvenators it gave similar laboratory results ensuring fulfilment of all requirements currently used in Poland.

The study shows that use of rejuvenators is, however, a problematic issue based on finding proper additive and its quantity to ensure fatigue resistance of the mix and not to deteriorate the rutting resistance too much.

The attempt to use black diagram, created on the basis of data obtained from HMA stiffness test (phase angle and stiffness modulus) gave interesting results, enabling to exclude one of not compatible rejuvenators. Nevertheless, the method should be further investigated as second only one of two not compatible rejuvenators were noticed.

There is still need to carry on with studies in field of RAP recycling. It is planned to develop rejuvenator's efficiency evaluation method and to carry on with tests on almost 100% RAP HMA, broadening tests with different types of RAP and rejuvenators.

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