Asphalt recycling and foam bitumen – a combined approach

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ABSTRACT

To save resources and reduce the energy consumption during asphalt mix production there are three main approaches: addition of reclaimed asphalt (RAP), lower production temperatures, and reduced moisture content in raw materials. Whereas a high moisture content only influences, thus increases the energy consumption and emissions in the plant, RAP addition and lower production temperatures have a direct impact on asphalt mix properties.

The main goal of this study is the production of high quality asphalt mix. Experience has proven that high ratios of reclaimed asphalt can be incorporated into hot mix asphalt at equal quality. Furthermore using foam bitumen to produce warm mix allows mixing and compaction at reduced temperatures with comparable properties to hot mix. Combining asphalt recycling and foam bitumen is a step forward to an efficient and sustainable use of resources.

The feasibility of producing high quality warm mix asphalt with foam bitumen and various high RAP percentages was demonstrated in field trials. In several asphalt mixing plants mixes were produced, paved and compacted at reduced temperatures. Asphalt production and laying was attended and analyzed. Additionally, for direct comparison construction sites with conventional hot mix were observed. Mechanical mix properties equal to hot mix asphalt were found independent of the RAP content and production temperature.

Keywords: Energy saving, Environment, Foam, Reclaimed asphalt pavement (RAP) Recycling, Warm Asphalt Mixture

1. INTRODUCTION

Addition of reclaimed asphalt (RAP), lower production temperatures (WMA), and reduction of the moisture content in raw materials are the three main approaches to save resources, reduce the energy consumption and CO_2 footprint during asphalt mix production. Whereas a high moisture content only influences, thus increases the energy consumption and emissions in the plant, RAP addition and lower production temperatures have a direct impact on processes and asphalt mix properties.

In Europe during the last 30 years the amount of re-used reclaimed asphalt (RAP) increased steadily and in some projects reached close to 100 % [5]. For many years the plant technology has been ready to process high amounts of RAP [3]. The main reasons to use RAP are raw material shortage, economical reasons and environmental aspects. Depending on the country, course, type of asphalt plant, etc. the maximum allowed and possible amount of RAP varies. Apart from regulative and plant technical maximum amounts of RAP in the mix, also quality limits exist:

a) RAP characteristics: round/crushed aggregate, aggregate size distribution, binder properties & amount
b) RAP homogeneity
c) RAP temperature: depending on mixture temperature

Experience has proven that high ratios of reclaimed asphalt can be incorporated into hot mix asphalt at equal quality. Anderson et al. collected data across the US regarding the long term performance of high RAP sections (20 – 72 % RAP). In many cases high RAP sections have performed to a level equivalent to that of a virgin section, in several cases have even outperformed sections without RAP. Some high RAP sections exhibited a slightly higher degree of cracking and lower ride quality but these differences were not always statistically significant [1]. In another study 5 experimental sections were in-depth investigated by Hong et al. The long term in-service pavement performance with 35 % of RAP demonstrated a higher amount of cracking, less rut depth, and similar roughness change compared to virgin sections after about 16 years [6]. Some countries differentiate between hot and cold RAP addition. Findings from Germany showed no difference of hot and cold RAP addition of 25 % and 20 % to wear and binder courses compared to virgin HMA after 19 years in the road [7]. In extended laboratory trials mixtures with RAP contents of up to 80 % were analyzed for 3 different courses. No negative influence of the RAP addition was found as long as the required mixture characteristics were met. To even further extend the limits for high recycling contents separation into different RAP size fraction is necessary. Additionally depending on the RAP binder characteristics, the use of rejuvenators becomes necessary to meet the binder specifications [12].

The second important green technology is warm mix asphalt (WMA). WMA technologies are applied to reduce emissions on plant and construction site, save fuel, increase compaction efficiency, and enhance occupational safety. A wide range of technologies exists to produce WMA: a) bitumen foaming; b) introducing water, chemicals, waxes as lubricant; c) emulsions; or d) changing the mixing sequence. Methods vary widely but the aim of all these technologies is a reduction of the production, paving, and compaction temperature of the asphalt [9],[4]. In this study the focus is on foamed bitumen and the resulting WMA. The use of foamed bitumen to produce warm mix allows mixing and compaction at reduced temperatures with comparable properties to hot mix. Foam bitumen is produced by injection of water into the hot bitumen (see Figure 1). No additives are used which makes it one of the most environmental friendly technology. Foamed bitumen asphalt can improve the following characteristics compared to HMA:

a) Softer binder
b) Higher degree of compaction
c) Higher “filled voids” / lower “air void” value
d) Higher Marshall flow

Many studies on WMA exist but only a limited number of reports on field trials and long term performance with foam bitumen. 2000 – 2003 several test sections were produced and paved by Larsen et al. With proper paving techniques applied, the mechanical properties of the WAM® foam mixture were equal to those of HMA. Also on the road the WAM® foam and the HMA sections were alike in terms of (average) rut depth, longitudinal smoothness and surface texture [10]. In accelerated pavement testing facilities and field tests a variety of foaming technologies have been tested under heavy loading conditions. The WMA mixes provided similar response like HMA under traffic and climate changes, and were not susceptible to moisture damage even under saturated conditions [11]. In a field trial study Bieder et al. found the required number of roller passes to reach the final compaction and the mechanical properties of the WMA asphalt similar to HMA and according to the Swiss standards [2]. Additionally no degradation of the pavement or rutting was observed after 5 years.

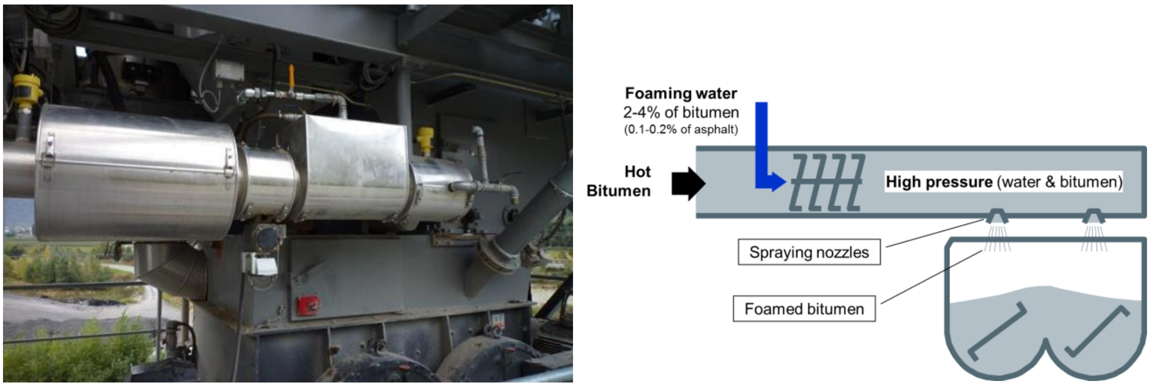

Figure 1: Foam generator installation on conventional mixing plant to the left, and to the right an illustration of the foam generator – key element to produce high quality foam asphalt mix

A step further in reducing the energy consumption and CO_2 footprint goes the combined approach of high ratios of reclaimed asphalt and warm mix asphalt. The advantages of this combination are the lower required RAP temperatures and a reduced binder aging due to the lower material temperatures by using a WMA technology. But due to the lower temperatures the viscosity of the harder RAP binder might not decrease sufficiently to ensure complete mixing of the old and new binder. It was shown by Kriz [8] that the reduced bitumen diffusion coefficient at WMA temperatures (100 °C) is not sufficient to completely mix the binder originating from the RAP material and the freshly added bitumen. Areas with hard and brittle old binder are inhomogeneous and can result in a shorter service life and adhesion problems. Therefore a new process with pre-treatment of the RAP material based on the Shell WAM® foam process was developed to maximize the fraction of recycled material while maintaining a performance level like conventionally produced asphalt with 60 % RAP addition [14]. A large number of studies exist with low RAP contents of 10 – 15 % and WMA but only few studies added a high RAP percentage with conventional processes combined with foaming technologies: WMA and HMA mixtures with 50 % RAP have been tested under heavy loading conditions in accelerated pavement testing facilities. Field performance was excellent through the entire 2-year trafficking period for all sections [11]. A direct comparison of on-site compaction of WMA and HMA with 30 % RAP addition showed identical density evolution. Material characteristics were comparable, the Marshall stability and flow of the WMA slightly higher than for HMA [4]. In Sweden different courses with 5 – 30 % RAP were paved. The results show that the quality of WMA is comparable to HMA and fulfill the standards. Even if the ITSR was within tolerance limits, the results were lower for WMA than for HMA. Surprising was the analysis of the softening point as no difference was found [13].

The goal of this study is to show in field trials that WMA produced with foamed bitumen and up to 55 % RAP can be compacted similar to HMA, and that the rutting resistance of the pavement is similar for those two asphalt types. The combination of high ratio asphalt recycling and foamed bitumen is a step forward to a more efficient and sustainable use of resources.

2. CONSTRUCTION SITES

For this study two construction sites were closely monitored. The warm mix asphalt (WMA) and hot mix asphalt (HMA) of each course were produced and paved under comparable conditions. For each construction site regular WMA with foamed bitumen and HMA was produced in the same plant, then transported and paved in the same way, with identical equipment and staff. In this way, differences of the resulting pavement are reduced to the different production methods of the asphalt. In the case of plant and site A the WMA and HMA production took place on two different days with similar environmental conditions. Each course done at plant & site B was produced and paved consecutively on the same day, the different mixture types on two days running.

In Table 1 an overview of the produced and paved mixtures is given. The added amount of recycling material was 30 % and 55 %, respectively. In plant A all the reclaimed asphalt was added hot, in plant B 27.5 – 30 % and 25 – 27.5 % hot, and 20 – 22.5 % and 22.5 – 25 % cold, respectively. Cold RAP addition is a common way to lower production temperatures for WMA productions. The amount of cold RAP can be adjusted according to the temperature of the hot mineral in order to reach the desired asphalt temperature after mixing.

Table 1: Overview of monitored production and paving

	plant & site A	**plant & site B**	
Type	AC 16 N	ACT 22 N	AC 16 N
Temperature WMA / HMA [°C]	110 / 165	120 / 165	120 / 170
RAP total [%]	30	55	55
RAP cold [%]	-	20 – 22.5	22.5 - 25
Binder	B 70/100 S	B 70/100 S	B 70/100 S
Course thickness [cm]	6	9	5
Amount WMA / HMA [t]	1000 / 1000	280 / 225	150 / 120
Application road type	Rural road	Quarry road	Quarry road

The pre-compaction after the paver and the pavement density during compaction by the roller compactors was determined by nuclear density gauge measurements with a Troxler 3440 gauge. Therefore 15 s readings were done in the same spot after each roller pass, if possible. 4 spots across the road width were analyzed for each measuring position (Figure 2). The compaction evolution was analyzed by a logarithmic fit

$$\%\text{-Marshall density} = A \cdot \ln N + C$$

where A is a parameter of the compaction efficiency, N the current number of roller passes or time, C the fitted pre-compaction after the paver.

Climate data were recorded by a mobile meteorological station set up next to the construction site. All mixture and drilling core analysis were done according to the European hot mix standard EN 13108-1:2006 / AC: 2008. Rutting irregularities were determined by a 4 m straight edge according to standard SN 640 516-7a (EN 13036-7: 2003).

Figure 2: Density measurements measurements are done after each roller pass (right) using a nuclear density gauge (left).

3. RESULTS & DISCUSSION

3.1 Climate

The climate differences for plant & site A were negligible, only the wind on day 2 during WMA laying was slightly stronger. For plant & site B the temperatures during WMA and HMA paving were considerably different as can be seen in Figure 3. During WMA paving in the morning the ground was frozen and underground temperatures < 0 °C. The air temperatures were 2 – 8 °C during WMA and 8 – 10 °C during HMA paving in the afternoon. As the solar radiation was high these days in the afternoon the underground temperatures were even higher than the ambient temperatures.

In general no negative influence on the compaction was found as long as the compaction started immediately after the paver laid the material. However as waiting times arose, especially for thin wear courses the material will quickly cool down to temperatures at which the compaction density requirements are difficult to fulfill.

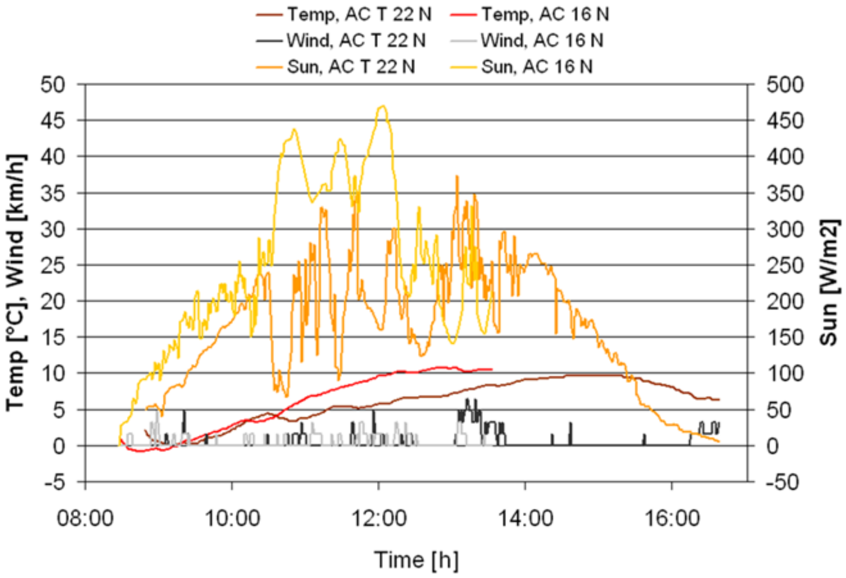

Figure 3: Temperature, wind speed and solar radiation during paving

3.2 Compaction evolution & end compaction

The temperature of the asphalt mixture delivered to the construction site was highly homogeneous for both construction sites and all mixtures. The asphalt temperatures measured in the paver hopper are listed in Table 1. An example of the evolution of the compaction density of AC 16 N on site B can be seen as a function of roller passes and time in Figure 4 and Figure 5, resp. The compaction efficiency A of all measured spots is shown in Table 2 as an average value and its standard deviation. From these results it is obvious that the compaction efficiency for WMA and HMA is identical. Even with high RA contents of up to 55 % and up to 25 % cold RA addition only 5 – 10 roller passes are enough to reach the minimum of 97 % - Marshall density. According to the European hot mix standard after compaction a minimum of 97 % - Marshall density has to be reached for individual spots and an average of 98 %. In Figure 6 and Table 2 the results of the drilling cores taken at construction site A and the end density measured by Troxler gauge at site B are shown. All measurements reached the required compaction values. Additionally the achieved end compaction is identical for all types of asphalt mixtures.

Table 2: Compaction efficiency A depending on roller passes and time

site	mix type	mix class	roller passes [-]		time [h]	
			average	stdev	average	stdev
A	AC 16 N	WMA	2.42	0.36	2.48	0.31
		HMA	2.48	0.40	2.61	0.50
B	ACT 22 N	WMA	2.71	0.34	3.28	0.34
		HMA	3.06	0.44	3.37	0.56
B	AC 16 N	WMA	2.61	0.18	2.91	0.01
		HMA	2.68	0.09	2.81	0.15

Table 3: Reached end compaction of drilling cores or nuclear density gauge measurements (4 x 1 min reading at each measurement spot)

site	mix type	mix class	method	end compaction [%]	
				average	stdev
A	AC 16 N	WMA	core	100.0	0.3
		HMA	core	99.7	0.4
B	ACT 22 N	WMA	gauge	100.6	0.9
		HMA	gauge	99.6	1.6
B	AC 16 N	WMA	gauge	99.9	0.4
		HMA	gauge	100.0	0.4

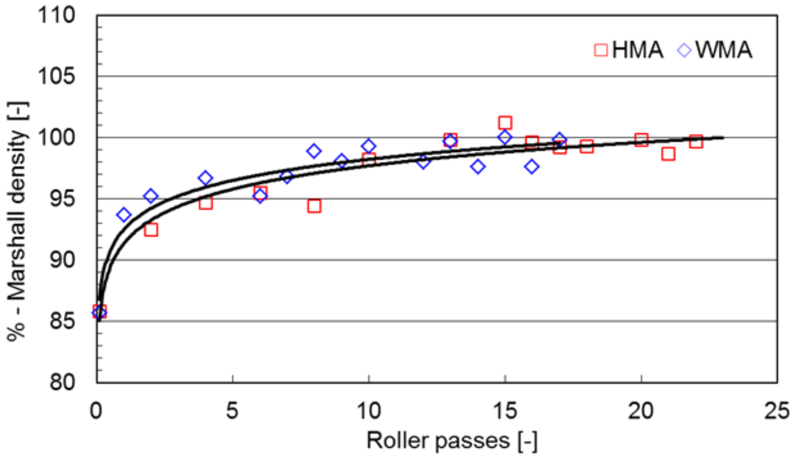

Figure 4: Compaction evolution WMA and HMA vs. roller passes (site B, AC 16 N)

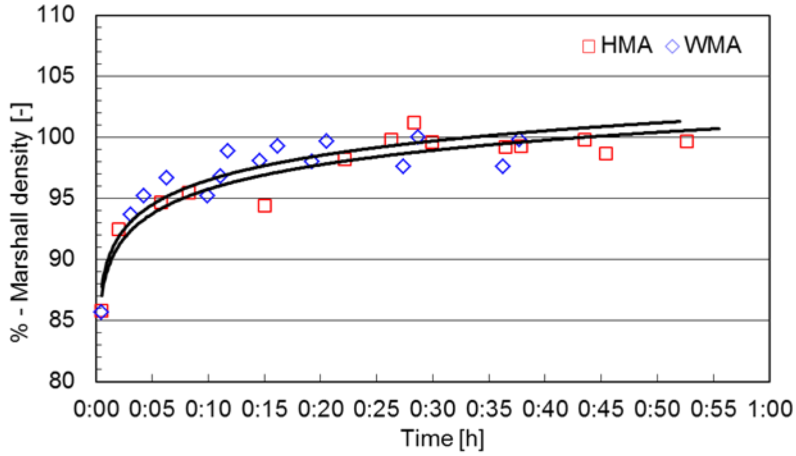

Figure 5: Compaction evolution of HMA and WMA vs. time (site B, AC 16 N)

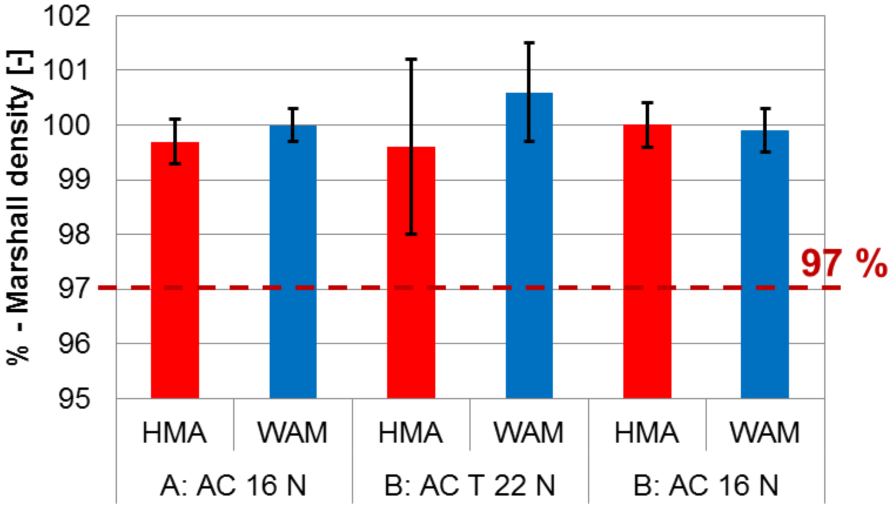

Figure 6: End compaction, site A: drilling cores, site B: nuclear density gauge

3.3 Mechanical mixture properties

In general the mixtures reached the required mechanical properties according to the European standards as shown in Table 4. For AC 16 N from both plants the filled voids exceeded the allowed percentage and for the mixtures produced in plant B the flow was too high. The filled void and flow was also too high for the reference material without RAP addition, thus the mix design should be adapted to reach the specifications in the standards.

Table 4: Mixture analysis according to standard EN 13108-1: 2006 / AC: 2008

	AC 16 N					ACT 22 N		
	Req.	**plant A**		**plant B**		**Req.**	**plant B**	
		HMA	**WMA**	**Reference (no RAP)**	**WMA**		**Reference**	**WMA**
Filled voids [%]	≤ 83	81.9 85.8	83.0 87.1	85.9	82.7 83.3 81.9	≤ 80	73.3	76.0
Void content [%]	2 – 5	2.8 2.1	2.5 1.9	2.1	2.6 2.5 2.7	3 – 6	3.8	3.3
Stability [kN]	≥ 7.5	9.8 9.8	10.3 12.1	10.5	9.7 10.6 9.7	≥ 7.5	12.5	10.2
Flow [mm]	2 – 4	2.9 3.0	3.6 3.1	4.7	4.4 4.2 4.3	1.5 – 3.5	4.4	4.2

3.4 Rutting

Rutting was analyzed after compaction, after 22 and 43 months for site A and 16 and 40 months for site B, resp. Even after more than 3 years both roads and neither section showed rutting or degradation of the pavement (Figure 7). Especially at site B the result is significant as the quarry road is trafficked by heavy loaded trucks.

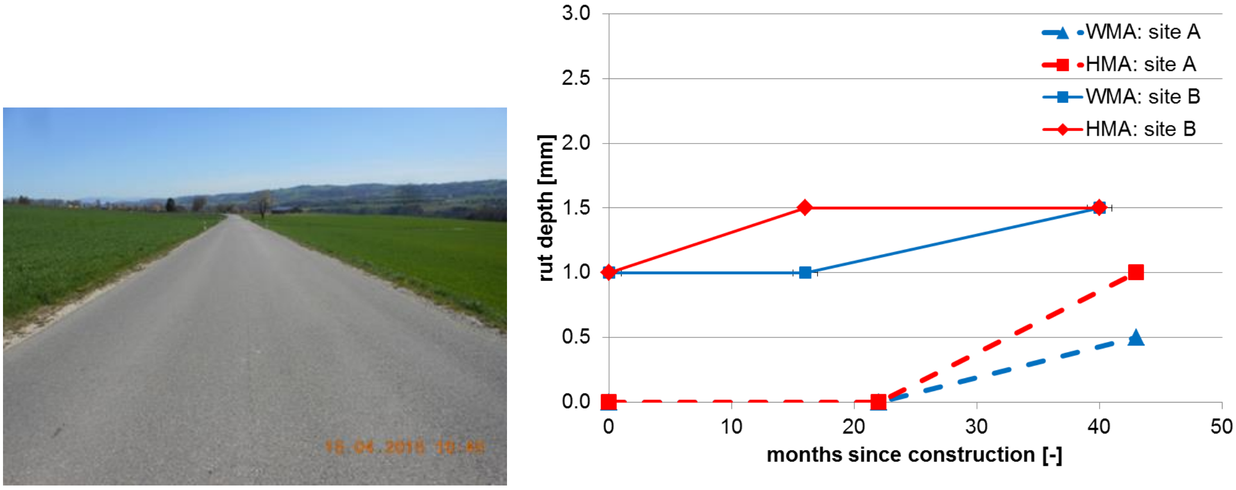

Figure 7: WMA road paved 43 months ago (left), and rutting for site A and B.

4. SUMMARY & CONCLUSIONS

It was demonstrated in field trials that compared to hot mix asphalt, warm mix asphalt with foamed bitumen and various high RAP percentages can be compacted to the same density level, and the rutting resistance and visual aspect of the pavement after more than 3 years are similar. In two different asphalt mixing plants several mixes were produced, paved and compacted at reduced temperatures. Asphalt production and laying was attended and analyzed. In addition, for direct comparison construction sites with conventional hot mix asphalt were observed. Considering the specific mechanical mix properties evaluated for this work, equivalent results were obtained for both HMA and WMA produced with foamed bitumen and containing up to 55 % RAP.
WMA can be produced with 30 % and 55 % RAP at 110 °C and 120 °C, respectively, with the same quality as HMA. Additionally the high RAP content does not degrade the quality of any of the asphalt mixtures. By adding cold RAP the production temperature flexibility of the plant is enhanced and additionally by using RAP and foam the RAP temperature can be lowered from 160 – 170 °C to 110 – 120 °C. This is beneficial as the heating ages the binder and has a hardening influence on the binder properties.

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