FIELD AND LABORATORY EVALUATION OF WARM MIX ASPHALT PRODUCED WITH RUBBERIZED BITUMEN: ASPHALT PROPERTIES AND ENERGY SAVINGS

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ABSTRACT

In recent years, warm mix asphalt (WMA) is widely used for reducing energy requirements and emissions in comparison to hot mix asphalt (HMA) industry. Besides, the use of rubberized bitumen has been spread out mainly due to environmental aspects, but high mixing and compaction temperatures are necessary due to the higher viscosity of this type of bitumen. A WMA mixture (using a surfactant technology) with asphalt rubber was evaluated in a field project, together with a control section. WMA mixing and placing temperature was 25ºC lower than HMA. Tensile indirect strength, resilient modulus and moisture-induced damage tests were conducted with the mixture collected in the plant. WMA test results showed similar behavior to HMA. In addition, a simplified estimate of decreasing in fuel consumption in the plant was also determined and the results showed that the use of WMA was advantageous.

Keywords: Warm mix asphalt, rubberized bitumen, field evaluation, laboratory evaluation, energy savings

1. INTRODUCTION

The use of modifiers in the asphalt, such as rubber, has increased significantly in recent years. Reclaimed rubber may not only help to deal with the great amount of tires discarded every year, but also improve some bitumen properties. The primary purpose of using rubber in asphalt is to obtain a stiffer mix at high service temperatures, a more elastic asphalt to resist fatigue cracking at intermediate service temperatures, and a lower or unchangeable stiffness at low service temperatures to resist thermal cracking [1]. However, due to the higher viscosity of the asphalt rubber, the mixing temperature must be higher than non-modified asphalt, increasing stack emissions and the fuel consumption [1]. On the other hand, warm mix asphalt (WMA) has been gaining increasing popularity in the paving industry, in order to reduce the temperatures at which asphalt is produced and placed about 30°C or more [2]. Lower temperatures mean that any emissions, either visible or non-visible that may contribute to health, odor problems, or greenhouse gas emissions, will be reduced and will represent significant cost savings if considering that 30-50 percent of overhead costs at an asphalt plant can be attributed to emission control [3]. Besides, lower mixing temperatures at the plant mean fuel cost savings: findings have shown that lower plant temperatures can lead to a 30 percent reduction in energy consumption [3].

WMA technologies have been introduced in Europe in 1997, in the United States in 2002 [2] and in Brazil some studies and projects were carried out only after 2006 [4]. In this context, the use of WMA as a paving technique is recent and has been largely studied [2, 5, 6]. The goal with WMA is to produce mixtures with similar strength, durability, and performance characteristics as conventional hot mix asphalt (HMA), yet using substantially reduced production temperatures (NCHRP, 2011), since there will no longer term environmental benefits or energy savings if WMA does not perform so well on a life-cycle basis in comparison with HMA [6].

Although tests in laboratory are important for measuring material responses in order to correlate them with pavement performance, the application in the field is essential for validating it. This paper presents the evaluation of a field project in which a WMA section was constructed in a highway along with a HMA control section. The asphalt materials were composed of gap-graded gradation and rubberized binder and a surfactant liquid additive was the WMA technology employed on this project. Loose mixture samples were collected at the plant, molded and evaluated in laboratory through indirect tensile strength, resilient modulus and moisture-induced damage tests. In addition, as the mixing temperature for WMA was 25°C lower than HMA, a simplified estimate of decreasing in fuel consumption was also carried out.

2. PROJECT DESCRIPTIONS

The field trial in Campinas city, Sao Paulo state from Brazil, was conducted on Bandeirantes Highway, a three-lane road through a heavily trafficked area which is under private concession since 1998 (Grupo CCR). The average daily traffic in 2009 was over than 30,000 vehicles (around 27% of trucks).

The project consisted in overlay the old asphalt pavement with new asphalt (30-mm thickness), in order to improve the pavement surface texture/friction. Paving works began in July 2010 and was finished in September 2010. The HMA section was divided in two parts and the WMA section was constructed between them. One should mention that both HMA sections are equal (the same materials). The layout of the trial sections are shown schematically in Figure 1.

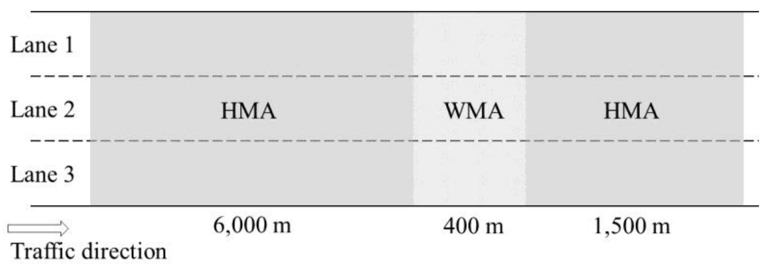

Figure 1: Layout of the trial sections

3. MATERIALS

The asphalt design was performed for the HMA according to Marshall method (75-blow specimens) and the mixture was based on the Caltrans asphalt-rubber hot mix – gap-graded (ARHM-GG). The optimum binder content (OBC) was defined as the amount of binder required to achieve 5.0% air voids. For the WMA, the same design was used likewise reported in previous researches [6, 7, 2].

The aggregate consisted of granite/gneiss material and hydrated lime, and the nominal maximum aggregate size was 9.5 mm. A bitumen supplier provided the binder modified with 20% of crumb rubber (one of the common types sold in Brazil, commercially named Ecoflex A). The design gradation and the OBC used for both asphalt materials are presented in Table 1.

Table 1: Design gradation and the optimum binder content

Sieve size [mm]	Percent passing [%]
12.5 (1/2")	100.0
9.5 (3/8")	96.9
4.75 (#4)	37.0
2.36 (#8)	23.9
1.18 (#16)	18.4
0.6 (#30)	12.4
0.3 (#50)	10.1
0.15 (#100)	7.6
0.075 (#200)	5.3
OBC [%]	**6.5**

The bitumen supplier previously blended the surfactant additive with the binder for the WMA, at a rate of 0.4% in mass of bitumen. This warm asphalt additive produced in Brazil (commercially named Gemul XT14) is a tensoactive agent composed of synthetic amides and allows reducing the mixing temperature around 25 to 30°C.

4. CONSTRUCTION

The construction was performed using typical practices (with the exception of temperatures), so as to evaluate the performance of WMA under usual construction conditions. In order to address a lower temperature for WMA during the mixing process, the temperature for drying aggregates was reduced, while the temperature for heating bitumen was maintained as usual. A batch plant was used in this project and the paving work was carried out during the day. Table 2 presents supplementary information about the construction, such as time period and amount of material produced (approximate values), as well as mixing and compaction temperatures.

Table 2: Supplementary construction information

	HMA	WMA
Time period for construction [days]	17	3
Amount of asphalt produced [tons]	5700	450
Mixing temperature [°C]	170 - 180	140 - 150
Compaction temperature [°C]	155 - 175	130 - 150

Although the reduction of temperature for producing and placing the WMA, no additional difficulties were reported throughout the construction: mixing and laydown operations for WMA and HMA sections were similar. This was an important aspect observed, since paving work with asphalt rubber in lower temperatures could be more complicated, due to the higher viscosity of the bitumen.

On the other hand, a distinctive feature between them was the reduction in visible fumes emissions during the placement of WMA in the field (Figure 2), the same situation observed by [8]. According to [9], tests for bitumen aerosols/fumes and polycyclic aromatic hydrocarbons (PAH) indicated significant reductions with WMA compared to HMA, with results showing a 30 to 50 percent reduction (although exposure data for conventional HMA were below the current acceptable limits). In addition, these authors also mentioned that emissions in plant are typically reduced in 30 to 40 percent of CO_2 and sulfur dioxide (SO_2), 50 percent for volatile organic compounds (VOC), 10 to 30 percent for carbon monoxide (CO), 60 to 70 percent for nitrous oxides (NO_x) and 20 to 25 percent for dust.

Figure 2: Reduction in visible emissions when paving WMA (left) and HMA (right)

5. TEST RESULTS

5.1 Field compaction

Cores were taken at each site (in a random manner) to determine the initial compaction properties of the asphalt materials, such as field density (according to AASHTO T166-07), air voids and thickness. Along HMA and WMA sections, a total of 145 and 16 cores were taken, respectively. The average results are presented in Table 3 (values in parentheses represent standard deviations).

Table 3: Compaction results

	HMA	WMA
Field density [%]	98.6 (± 0.6)	99.2 (± 0.4)
Air voids [%]	6.1 (± 0.8)	5.9 (± 0.5)
Thickness [mm]	3.5 (± 0.5)	3.9 (± 0.4)

An Analysis of Variance (ANOVA) was conducted on the data to determine if the WMA section was significantly different from the HMA. Results from the analyses concluded that while the air voids were statistically the same, field density and thickness were considered different. Despite these differences, the compaction properties may be considered similar, since HMA and WMA demonstrated close results.

5.2 Indirect tensile strength and resilient modulus

Loose mixture samples of HMA and WMA were collected at the plant, molded and evaluated in laboratory through mechanical tests, such as indirect tensile (IDT) strength and resilient modulus (RM), in accordance with ASTM D6931-07 and ASTM D7369-09, respectively.

HMA and WMA loose samples were reheated at 165 and 140°C, respectively, (average temperatures verified in the field) and then compacted using the Marshall method. Five specimens were produced for the IDT strength test, while three were prepared for the RM test.

According to the Brazilian standard DNIT ES112/09, the minimum IDT strength specified for gap-graded rubberized asphalt (at hot temperature) is 0.50 MPa. On the other hand, Brazilian specifications for asphalt do not consider maximum or minimum limits of RM, yet this mechanical property has been widely used in studies of structural behavior of pavements.

IDT strength and RM tests were conducted at 25°C and the average results are reported in Table 4. The air voids content was previously determined, according to AASHTO T166-07, and the average results are also presented in Table 4 (values in parentheses represent standard deviations).

Table 4: Indirect tensile strength and resilient modulus results

	Indirect tensile strength [MPa]	Air voids [%]	Resilient modulus [MPa]	Air voids [%]
HMA	0.91 (± 0.14)	7.3 (± 0.2)	1,631 (± 9)	7.2 (± 0.1)
WMA	0.82 (± 0.05)	7.3 (± 0.1)	1,756 (± 46)	7.4 (± 0.1)

Although WMA presented a slightly lower IDT strength than HMA, both results are close and so WMA behavior can be considered comparable to HMA. In addition, WMA was observed to be in compliance with the Brazilian standard previously mentioned (for hot mixes).
In terms of RM, despite a slightly difference concerning the average air voids content, WMA and HMA also presented close results of RM and their behavior may be considered similar too.

5.3 Moisture-induced damage

If the moisture contained in the aggregate does not completely evaporate during mixing due to the lower mix temperatures, water may be retained in the aggregate and susceptibility to moisture damage could be increased [3]. Therefore, loose mixture samples of HMA and WMA were tested, according to AASHTO T283-07, to assess their potential for moisture susceptibility. Besides, according to that specification, air voids content of all specimens must be between 6 and 8% (7% ±1%) in order to address their partial saturation.
HMA and WMA loose samples were reheated at 165 and 140°C, respectively, and then compacted by Marshall method. Eight specimens were produced for HMA and six were prepared for WMA, in which half of them were used as a control group of specimens and the other were conditioned to water (including freeze cycle) before being tested.
According to the Brazilian standard DNIT ES112/09, the minimum tensile strength ratio (TSR) specified for gap-graded rubberized asphalt (at hot temperature) is 0.7, which means that asphalt should lose no more than 30% IDT strength after being subjected to moisture-induced.
The results obtained for HMA and WMA are presented in Table 5, which contains air voids content, IDT strength before and after conditioning (numbers in parentheses represent standard deviations) and TSR value.

Table 5: Moisture resistance results

	Not conditioned		Conditioned		Tensile Strength Ratio
	Indirect tensile strength [MPa]	Air voids [%]	Indirect tensile strength [MPa]	Air voids [%]	
HMA	0.91 (± 0.14)	7.3 (± 0.2)	0.81 (± 0.08)	7.2 (± 0.1)	0.89
WMA	0.82 (± 0.05)	7.3 (± 0.1)	0.74 (± 0.05)	8.0 (0)	0.90

WMA showed comparable- resistance to moisture induced damage to HMA Additionally, WMA was found to be in compliance with the Brazilian standard previously mentioned (for hot mixes).

6. ESTIMATE OF ENERGY SAVINGS

Mixing and compaction procedures used for WMA in this study were similar to the conventional practices for HMA, except in terms of reducing temperature of aggregate during the mixing process. Hence, it is presented a simple estimate of the energy saved, in comparison with HMA. Accordingly, a fuel cost savings estimate was also possible to be carried out. The estimate was focused on the reduction of temperature for drying/water vaporization/heating aggregates, since these procedures demand a large amount of energy in the mixing plant, especially if moisture content of aggregates is high. Literature [2] mentioned that fuel usage has been reported to be increased 10 percent for every 1 percent increase in aggregate moisture content.
The calculation of the energy demand was conducted as presented by [10] and [11], after fixing some values (Table 6) and using expressions (1) to (4).

Table 6: Values fixed for estimating energy savings

	Value
Specific heat of aggregates (Q_a)	0.85 kJ/kg/°C
Mass of aggregates (m_a)	420750 kg*
Heating temperature of aggregates (t_a)	145°C for WMA and 180°C for HMA
Ambient temperature (t_{amb})	25°C
Specific heat of water (Q_w)	4.2 J/kg/°C
Moisture content of aggregates (h)	3%
Specific heat of steam (Q_s)	1.85 J/kg/°C
Latent heat of vaporization (L)	2250 kJ/kg/°C

* The mass was based on the amount of WMA produced for the project (Table 2) and on the mix design (93.5% of aggregates and 6.5% of bitumen)

- Energy for heating aggregate [kJ]

$$Q_a \cdot m_a \cdot (t_a - t_{amb}) \quad (1)$$

- Energy for heating water [kJ]

$$Q_w \cdot \left(\frac{m_a}{m_a - \frac{h}{100} \cdot m_a} - 1 \right) \cdot m_a \cdot (100 - t_{amb}) \tag{2}$$

- Energy for vaporizing water [kJ]

$$L \cdot \left(\frac{m_a}{m_a - \frac{h}{100} \cdot m_a} - 1 \right) \cdot m_a \tag{3}$$

- Energy for heating steam [kJ]

$$Q_s \cdot \left(\frac{m_a}{m_a - \frac{h}{100} \cdot m_a} - 1 \right) \cdot m_a \cdot (t_a - 100) \tag{4}$$

Table 7 presents the estimate of energy required for drying/vaporizing moisture/heating aggregates for producing 450 tons of WMA (amount used in the project), in comparison to the same mass of HMA.

Table 7: Estimate of energy required during drying/water vaporization/heating aggregates (for 450 tons of asphalt)

	HMA	**WMA**
	Estimate of energy required [MJ]	
Heating aggregates	55434	42917
Heating water	4099	4099
Vaporization of water	29279	29279
Heating steam	1926	1083
TOTAL	**90738**	**77378**
Energy savings with WMA [%]	**15**	

The batch plant in the project of Bandeirantes Highway works with fuel oil and normally uses an average of 5.5 kg of fuel per ton of HMA. Considering that average and energy savings of 15% (Table 7), the average fuel consumption with WMA should decrease to 4.7 kg/ton. This means that HMA and WMA required approximately 2.48 and 2.11 tons of fuel oil, respectively, for drying/water vaporizing/heating aggregates (in 450 tons of asphalt). In this context, as the fuel oil was usually bought at € 0.60/kg at that time, costs with fuel for HMA and WMA were € 1440 and € 1230, respectively, which means energy savings of € 210 (approximate values). However, it is important mentioning that all results were obtained considering those fixing values and may vary according to some issues, such as ambient temperature, heating temperature of aggregates or moisture content of aggregates.

7. CONCLUSIONS

WMA Project was successfully conducted as an overlay on a heavy duty Highway in Brazil. No additional difficulties were reported during mixing and laydown operations of WMA, in comparison with HMA section. This was an important issue, since working with asphalt rubber in lower temperatures could be more complicated, due to the higher viscosity of the bitumen.
A positive aspect verified during the placement of WMA in the field was the reduction of visible fumes emissions.
The results of field compaction for WMA and HMA were similar and demonstrated that WMA presented comparable behavior to HMA in terms of compaction.
Tests in laboratory for evaluating mechanical properties – indirect tensile strength and resilient modulus – and moisture-induced damage also showed that WMA and HMA performed in a similar manner.
An estimate indicated that the reduction of temperature for drying/vaporizing water/heating aggregates in the WMA mixing process provided energy savings of 15% approximately in the project. It is important mentioning that this estimate rate was obtained for some fixed values and may vary depending on some aspects, such as ambient temperature, heating temperature of aggregates or moisture content of aggregates.
Overall, warm mix asphalt containing rubberized bitumen demonstrated to be similar to conventional hot mix asphalt in terms of paving practices and also concerning some asphalt properties, yet reducing emissions and fuel consumption (especially in this case with modified bitumen in which mixing and placing temperatures are the highest for bituminous

materials). Not to mention that the use of crumb rubber may help to deal with the great amount of tires discarded every year worldwide.

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REFERENCES

[1] BROWN, E. R., KANDHAL, P. S., ROBERTS, F. L., KIM, Y.R., LEE, D.-Y., KENNEDY, T. W. Hot mix asphalt: Materials, mixture design, and construction. Lanham: NCAT at Auburn University, 3rd ed., 2009.
[2] PROWELL, B. D.; HURLEY, G. C. Warm-mix asphalt: Best Practices. Quality Improvement Series 125. Lanham: National Asphalt Pavement Association, 2007.
[3] HURLEY, G. C. Evaluation of new technologies for use in warm mix asphalt. 2006. 231 p. Thesis (MSc) – Auburn University, United States, 2006.
[4] MOTTA, R. S. Study of warm mixes asphalt as wearing courses for reducing pollutants emissions and energy consumption. 2011. 230 p. Thesis (PhD) – University of Sao Paulo, Brazil, 2011. (in Portuguese)
[5] AKISETTY, C. K.; LEE, S-J.; AMIRKHANIAN, S. N. High temperature properties of rubberized binders containing warm asphalt additives. Construction and Building Materials. 23. 565-573. 2009.
[6] SILVA, H. M. R. D.; OLIVEIRA, J. R. M.; PERALTA, J.; ZOOROB, S. E. Optimization of warm mix asphalts using different blends of binders and synthetic paraffin wax contents. Construction and Building Materials. 24. 1621-1631. 2010.
[7] GONZÁLEZ-LEÓN, J. A.; GRAMPRE, L.; BARRETO, G.; In: Transportation Research Board Annual Meeting, 88., Washington: TRB, 2009.
[8] BARTHEL, W.; MARCHAND, J.-P.; von DEVIVERE, M. Warm asphalt mixes by adding a synthetic zeolite. In: Eurasphalt & Eurobitume Congress, 3., 354, Vienna, 2004.
[9] D'ANGELO, J.; HARM, E.; BARTOSZEK, J.; BAUMGARDNER, G.; CORRIGAN, M.; COWSERT, J.; HARMAN, T.; JAMSHIDI, M.; JONES, W.; NEWCOMB, D.; PROWELL, B.; SINES, R.; YEATON, B. Warm-mix asphalt: European Practice. International Technology Scanning Program. Virginia: Federal Highway Administration, 2008.
[10] ROMIER, A.; AUDEON, M.; DAVID, J.; MARTINEAU, Y.; OLARD, F. Low-energy asphalt (LEA®) with the performance of hot-mix asphalt. In: Transportation Research Board Annual Meeting, 85., Washington: TRB, 2006.
[11] OLARD, F. Low energy asphalts. Routes Roads, n. 336-337, p. 131-145, 2008. World Road Congress: General Report and Conclusions: PIARC Prizes, 23., Paris, 2008.