Performance of asphalt-rubber hot mix overlays at Brazilian highway

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ABSTRACT: *This work presents a research program that aims at evaluating the performance of hot asphalt mix used in highway pavement rehabilitation with the addition of recycled rubber of tires. The objective of this study is to quantify the performance of asphalt mix when recycled rubber is added. This study will be based upon field tests to evaluate whether a relatively thin overlay with Asphalt Rubber (AR) could reduce reflective cracking. In 2001, the private agency Univias designed and carried out a large scale AR test project in Rio Grande do Sul, Brazil on the very heavily trafficked Interstate BR116. AR is a mixture of 88% hot paving grade asphalt and 12% ground tire rubber. This mixture is also commonly referred to as the asphalt rubber wet process. The overlay project was built on top of a very badly cracked concrete asphalt pavement. The performance of the asphalt rubber overlay surpassed the original expectation. This paper presents a brief history of asphalt rubber use and comparative results to evaluate the performance for hot-mix structural overlays, containing conventional or polymer-modified binders with similar applications containing asphalt rubber binder. After two years of service the overlay is still virtually crack free, with good ride, virtually no rutting or maintenance and good skid resistance. The findings indicate that asphalt rubber is cost effective.*

KEY WORDS: *Asphalt- rubber, field performance, bituminous mixtures, prediction models.*

1. Introduction

Today, the major concern of those in charge of the management of available financial resources invested in paving surely is the cost-effective feature of these resources.

Since the technology available related to the structures of asphalt pavement allows the identification of the main mechanisms that contribute to the decrease of durability of pavements throughout their service life, we are supposed to: (1) establish performance prediction criteria and models that make possible to estimate pavements service life in terms of the main mechanisms of deterioration, and (2) investigate the possibility of using new materials that meet the requirements of availability, economy and performance.

Several studies point out that the modification of the asphalt binders used in paving with addition of tire rubber is a technically and economically possible alternative for the improvement of the features of bituminous materials, especially regarding fatigue life, reduction of wear and aging.

The addition of tire rubber to the asphalt overlay of pavements has been used for some decades in the United States. Several researchers have reported experiments involving the use of asphalt mixes with tire rubber binders during the last few years (EPPS, 1994; HARVEY et al., 2000 and HICKS et al., 1999).Way (1999) has reported that in the American state of Arizona more than 3,300 km of highways were built or rehabilitated by means of rubber modified binders.

A typical new tire used in passenger cars weighs about 10 kg, and it is made of 85% of rubber and 12% of steel. When a tire needs to be replaced, its carcass still weighs about 9 kg, and it contains the same original amount of steel and canvas.

Regarding the environmental preservation point of view, the adequate handling of a material that became inappropriate for its original function is the production of a marketable subproduct that is useful for society.

Currently, in Brazil, there is not a significant use of tire rubber as the modifier of asphalt binders. According to the National Association of the Pneumatic Industry (*Associação Nacional da Indústria de Pneumáticos* - ANIP), Brazil produces 41.3 million tires a year. The main objective of this study is to assess the performance of different asphalt compositions used as rehabilitation overlay of a highway section exposed to heavy traffic and presenting severe deterioration status.

The planning and the current evolution status of a study that is being carried out with the objective of showing a comparative assessment of the performance of different asphalt binders exposed to stress produced by traffic loads in real scale are presented in this paper.

2. Experimental design

The on-going study includes the rehabilitation of three sections of Interstate BR 116 with three different asphalt compositions. The objective of this study is to investigate the behavior of different asphalt mixes used as overlay of the experimental sections.

The main variable to be investigated in the field is the kind of asphalt binder. Considering the use of three kinds of asphalt binders: conventional (CAP 20), polymer modified (SBS), and tire rubber modified (AR).

The experimental section is two thousand meters long. The rehabilitation was performed in August 2001. The overlay applied to the sections was 3.8 cm thick. The original asphalt coat presented severe cracks along almost its entire extent.

AR was modified by means of addition through the wet process of approximately 12% of the weight of pulverized tire rubber.The addition of rubber binder was carried out in an appropriate reactor and also through an adequate physical-chemical process that allowed the production of a stable asphalt rubber mix.

The modified binder presented new properties in terms of physical and rheologic behavior, which differed from the original binder. The properties of the rubber modified binder are shown in Table 1.

Table 1: Properties of rubber modified asphalt

Test	Value
Penetration (100 g, 5, 25°C), 0.1 mm	45
Softening point, °C	51
Elastic recovery, %	40
Flash point, °C	280
Relative density, 25°C/25°C	1.025
Brookfield viscosity at 135°C, cP	1040
Brookfield viscosity at 155°C, cP	340
Brookfield viscosity at 177°C, cP	148

3. Asphalt mix analysis

The design of the asphalt mixes was performed through the Marshall method, and it was complemented by resilient modulus, tension strength tests and fatigue life. The fatigue and controlled stress tests carried out in diametral compression were employed to design the following fatigue law:

$$N_f = K_1 \left(\frac{1}{s_t} \right)^n \qquad [1]$$

where σ_t is the horizontal tensile stress employed along the vertical diametral surface of the cylindrical specimens. The parameters of the fatigue law (K_1 and n) as well as the indirect tensile strength in diametral compression (S_T), the resilient modulus (R_M), both measured at 25^{o}C and the tensile rupture strain (ε_R estimated by S_T/R_M) are shown in Table 2.

These results show that the conventional asphalt mix exposed to the test can be classified as a hot mix asphalt pavement (HMA), and its mechanical properties can be considered normal, since the expected ε_R values are around 2.5×10^{-4}. However, the modified asphalt mixes present ε_R resistance higher than the normal value, tthat indicates that these materials present cracking resistance caused by fatigue higher than the resistance of conventional mixes.

Table 2: Results of mixes mechanic tests

Mix	K_1	N	R_M (MPa)	S_T (MPa)	ε_R (10^{-4})
Conventional	3.399×10^5	3.7831	3,392	0.9	2.65
Polymer	1.000×10^6	3.7032	3,981	1.2	3.06
Rubber	7.595×10^4	3.6224	2,702	0.9	3.37

The analysis of fatigue life under tensile stresses and strains cannot be directly performed using the K_1 and n parameters mentioned above, since K_1 value is affected by the velocity of load application, that is by the duration of the stress pulses produced by moving wheel loads. In addition, K_1 value also depends on the temperature of the asphalt mix. The analyses must be performed using the following fatigue law:

$$N_f = K\left(\frac{1}{e_t}\right)^n \qquad [2]$$

that is considering traction specific deformation (ε_t), since K parameter is virtually independent from the velocity of stresses application and it almost does not vary under different temperature. The conversion from a model to another is carried out taking into consideration that the vertical compression stress employed in the center of the cylindrical specimens of the diametral compression test is determined by: $\sigma_v = -3\sigma_t$. Therefore, one deduces that:

$$K = K_1\left(\frac{1+3u}{R_M}\right)^n \left(\frac{1}{e_t}\right)^n \qquad [3]$$

where υ is the Poisson's coefficient, which can be considered the same as 0.33 for asphalt mixes. The results are shown in Table 3, along with the maximal tensile strain measured through FLAPS (Finite Layer Analysis of Pavement Structures) software in the flexible pavement section shown in Figure 1, which was used as reference in order to assess the relative quality of the asphalt mixes analyzed with regard to resistance to fatigue cracking, in the portion of fatigue consumption that is produced by the tensile action on the asphalt layer. The ε_t values were measured in the lower fiber of the layer, in the vertical surface that goes through the center of a single wheel load of 41 kN.

Table 3: Fatigue consumption

Mix	K	n	ε_t (10^{-4})	N_f
Conventional	3.3325×10^{-11}	3.7831	2.795	926
Polymer	1.1804×10^{-10}	3.7032	2.600	2229
AR	8.1237×10^{-11}	3.6224	3.074	429

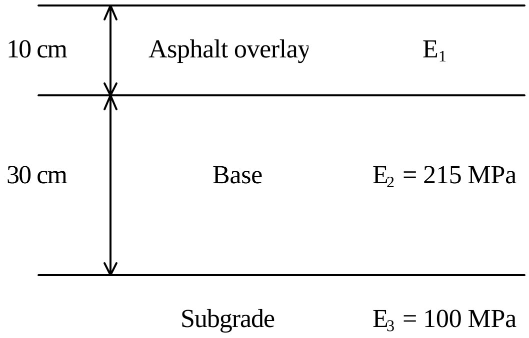

Figure 1: Reference pavement section for the analyses

For the elasticity modulus of the asphalt overlay (E_1), the calculations were made taking into consideration the resilient modulus (R_M) measured in diametral compression at 25^{0}C. The results show that with regards to the portion of resistance to the fatigue related to the tensile strength on the asphalt layer the polymer modified asphalt presents 2.4 folds higher resistance to the fatigue than the conventional HMA, while the asphalt rubber mix presents resistance of 46% of the tensile strength of the conventional HMA. However, these results take into consideration only the portion of fatigue life of the asphalt layer that is consumed by the tensile stress.

Depending on the stress distribution on the pavement structure, a significant portion of the fatigue consumption can be produced by shear stress that acts vertically along the asphalt layer. According to RODRIGUES (2000), in the flexible pavement, the fatigue consumption under the bending mode is greater than the fatigue consumption under the shearing mode, while in the asphalt concrete overlay applied over a severily cracked pavement it will appear a tendency for the shearing mode to be prevalent, specially when the cracked layer is thick relative to the asphalt concrete overlay.

This effect is taken into consideration in the Pavesys9 mechanistic-empirical performance prediction model developed by RODRIGUES (2000), which show the following results in terms of time period required for the first fatigue cracks to appear on the surface of the pavement (t_0) and the period of time, in years, until 20% of the pavement area is affected by fatigue cracks (CR):

- Conventional asphalt concrete: t_0 = 3.0 years; CR = 20% after 10.3 years;
- Polymer modified asphalt concrete: t_0 = 4.4 years; CR = 20% after 11.7 years;
- Asphalt Rubber: t_0 = 3.8 years; CR = 20% after 11.1 years.

for a case where the annual traffic load is given for: $ESAL_{year} = 5 \times 10^5$ equivalent operations of the highway standard axle of 8.2 tf (using the load equivalence factors of AASHTO), which corresponds to heavy traffic. The results still show that the polymer-asphalt mix is the most resistant among the three mixes, but they indicate an inversion of positions regarding the other two mixes, since the asphalt rubber mix is more resistant than the conventional HMA. This conclusion is consistent with the fact that rupture tensile strain of the modified mixes is higher than the conventional HMA.

The rutting parameter shows almost identical behaviors in the three cases (the critical value of 12 mm only would be reached after more than 20 years of service), while the PSI parameter shows a performance a little better for the asphalt-polymer mix (PSI critical value = 2.5 would be reached in 15.0 years) regarding the other mixes, which show virtually identical performance in this aspect (PSI = 2.5 in 13.5 years).

Table 4 shows the main properties of the asphalt mixes analyzed in this study. The mixes were produced by means of the same granulometry for the aggregated elements.

The most important parameter for the definition of fatigue resistance of an asphalt mix is the air-void volume. In this aspect, the fact that a polymer-asphalt mix presents the lowest V_V value among the three mixes contributes to make its fatigue resistance the highest of all, while the asphalt-rubber mix had a worse performance regarding the comparisons due to the fact that the specimens were produced with a higher air-void volume.

Table 4: Asphalt mixes used

Parameter	Conventional	Polymer	AR
Marshall stability (kN)	16.4	16.5	15.9
Flow (mm)	3.8	2.1	3.4
p_B (%)	6.1	6.1	6.1
V_B (%)	13.7	13.8	13.6
V_V (%)	3.5	3.0	3.9
VAM (%)	17.2	16.8	17.5

In Table 4:

p_B = mix binder contents, in weight;
V_B = mix binder contents, in volume;
V_V = mix air-void volume (% of volume);
VAM = aggregated mineral air-void volume = $V_V + V_B$.

4. Pavement Diagnosis

The structural and functional condition of the highway before the rehabilitation was identified during the pavement diagnosis phase. The Interstate BR 116 was constructed between 1958 and 1961. Today, it is one of the most important longitudinal highways in Brazil.

The section between the cities of Guaíba and Camaquã, where the section analyzed in this study is located, is part of the highway that connects the capital of the state of Rio Grande do Sul to the harbor of Rio Grande. The pavement of the section is made of hot mix asphalt pavement with 15 cm of thickness and base and sub-base of granite residual soil with 35 cm of mean thickness.

During the design of the pavement rehabilitation project mechanistic-empirical performance prediction models were applied in order to estimate the degradation evolution of the experimental sections regarding the main mechanisms that affect the end of the service life of flexible pavement structures, that is the occurrence of fatigue cracking and the presence of wheel rutting.

The performance models used are part of the Pavesys Pavement Management System, which is installed in the paved network of the Univias company since 2002. The paved network under the responsibility of Univias is approximately 1,300 km long.

The elasticity modules of the layers were determined by means of backcalculations of the basins of FWD measured under a load of 41 kN. The pavement structure considered for this calculation is the section shown in Figure 2, where the thickness values refer to the mean values determined through investigations performed in several points of the experimental section. The analysis that will be presented in this study considered the mean values of elasticity modules of the respective layers calculated for all experimental sections, as indicated in the last line of Table 5.

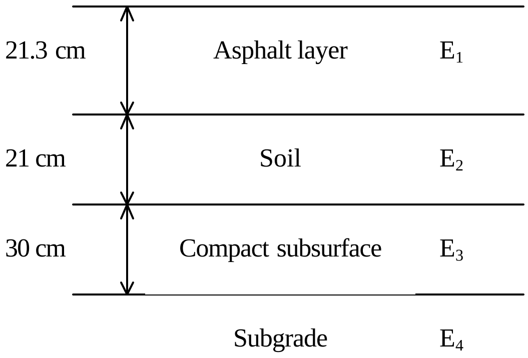

Figure 2: Pavement section for backcalculation of FWD

The values for E_1 determined using backcalculation were rather lower than the expected values for the resilient modulus measured in laboratory tests at 25^0C using conventional asphalt concrete samples (3000 to 5000 MPa), which might be a consequence of the layers severe cracking.

Table 5: Mean values for the modulus of elasticity

Section	E_2 (MPa)	E_3 (MPa)	E_4 (MPa)
01	77.5	676.1	197.5
02	146.0	442.7	258.9
03	94.6	743.9	346.3
04	130.4	704.4	320.0
Mean	112.1	641.8	280.7

The base layer presents moderate resilience, which might be a consequence of either the soils nature or its humidity level (due to water penetration through the overlay cracks). The sub-base soil, on the other hand, shows very low elastic deformability.

Taking into consideration that the annual traffic load is 5×10^5 repetitions of standard axle of 8.2 tf (according to the load equivalence factors of AASHTO) and that the local climate conditions can be expressed by the following mean monthly temperatures:

January: 23.6 ^{0}C
February: 23.9 ^{0}C
March: 23.8 ^{0}C
April: 19.7 ^{0}C
May: 17.6 ^{0}C
June: 12.2 ^{0}C
July: 12.8 ^{0}C
August: 15.0 ^{0}C
September: 15.0 ^{0}C
October: 17.5 ^{0}C
November: 19.2 ^{0}C
December: 22.3 ^{0}C

the following performance prediction for an asphalt rehabilitation layer with 3.8 cm of thickness, applied to the experimental section after cutting of 2.5 cm of the pavement, is produced:

- Conventional asphalt concrete: t_0 = 2.9 years; CR = 20% after 4.4 years;
- Polymer modified asphalt concrete: t_0 = 6.8 years; CR = 20% after 8.3 years;
- Asphalt Rubber: t_0 = 5.0 years; CR = 20% after 6.5 years.

5. Conclusion

The experimental section in the Interstate BR 116 might allow for an evolution of the knowledge about the use of tire rubber modified asphalt mixes in the south region of Brazil. The performance offered after two years of studies reveals the absence of severe defects in the rehabilitated sections. The degradation estimate of the experimental sections obtained through the application of performance prediction models and adjusted according to the observation of the behavior of the highways in service in Brazil were presented in this paper. The results of this study might be used for the assessment of the accuracy of the models employed and to identify the need of applying shift factors.

6. References

EPPS, J. A., 1994, Uses of Recycled Rubber Tires in Highways. In *NCHRP Synthesis 198*, TRB, National Research Council, Washington, DC, 162 pp.

HARVEY, J.; BEJARANO, M.; FANTONI, A.; HEATH, A. AND SHIN, H., 2000, *Performance of Caltrans Asphalt Concrete and Asphalt Rubber Hot Mix Overlays at Moderate Temperatures*. http://www.ksu.edu/pavements/trb/A2B09/index.htm. Accessed december 2, 2001.

HICKS, R.G., LUNDY, J.R. AND EPPS, J. A., 1999, *Life Cycle Costs for Asphalt-Rubber Paving Materials*. Final Report to Rubber avements Association, Vols. I/II.

RODRIGUES, R.M., 2000, *Performance Prediction Models for Highway and Airport Pavements in Brazil*, Research Report FAPESP No.1999/09012-2, Fundação de Amparo à Pesquisa do Estado de São Paulo, São Paulo, Brazil.

RODRIGUES, R. M., 2000, *A Model for Fatigue Cracking Prediction of Asphalt Pavements based on Mixture Bonding Energy*.. The International Journal of Pavement Engineering. Nottingham - UK: , v.1, n.2, p.133 – 149.

WAY, G., 1991, “Flagstaff I-40 Overlay Project”, 4R Conference & Road Show, Cincinnati, Ohio.

WAY, G., 1999, “Flagstaff I-40 Overlay Project: Nine Years of Success”, Transportation Research Board 78th Annual Meeting , Washington, DC.