Universidade do Minho

[CI-56]

Fontes, L.P.T.L., Trichês, G., Pereira, P.A.A., **Pais, J.C.**

"Comparison between asphalt rubber and conventional mixtures in overlay design"

4th Eurasphalt & Eurobitume Congress, Copenhagen, Denmark, 21-23 May, 2008

COMPARISON BETWEEN ASPHALT RUBBER AND CONVENTIONAL MIXTURES IN OVERLAY DESIGN

L.P.T.L. FONTES [1], G. TRICHÊS [1], P.A.A. PEREIRA [2], J.C. PAIS [2]

[1] *Departamento de Pós-graduação em Engenharia Civil, Universidade Federal de Santa Catarina, Rua João Pio Duarte, Florianápolis-SC, BRAZIL, 88040-970*

[2] *Departamento de Engenharia Civil, Vias de Comunicação, Universidade do Minho, Campus de Azurém, 4800-058 Guimarães, PORTUGAL*

ABSTRACT

Asphalt modified with crumb rubber has been used to produce asphalt rubber mixtures for pavement overlays subjected to heavy loads and high temperatures. Under severe conditions, these mixtures are capable of resisting permanent deformations, having an extended fatigue life and resisting crack propagation in comparison to conventional ones. A laboratory research was conducted to determine the performance properties of overlays with asphalt rubber mixtures produced through wet processes using a gap graded mixture. The asphalt rubber was prepared by the continuous blend process and its properties were measured by means of current tests. An identical study for a conventional mixture used as a reference was performed. An extensive study in which the mechanical properties of the studied mixtures were determined and compared was also carried out. The permanent deformation and the fatigue test of two different mixture designs manufactured with modified and conventional binders, with the same aggregates and different binder contents, were evaluated. The mechanical results from asphalt rubber and conventional mixtures were also compared by applying a pavement overlay design method that considers crack propagation from the existing pavement to the pavement overlay.

Keywords: overlays, rubber, fatigue cracking, permanent deformation

1. INTRODUCTION

Pavement overlaying consists of applying a layer of asphalt mixture over an existing structurally sound pavement. However, pavement structures become distressed and deteriorate as a result of many factors, such as fatigue, permanent deformation and reflective cracking. In order to design an overlay that is able to restore an old pavement increasing its level of serviceability and to provide the necessary structural strength for the project life, it is necessary to design a desirable asphalt mixture.

An asphalt rubber mixture pavement overlay represents a viable rehabilitation strategy. Rubber from waste tires has been used in asphalt mixtures since the late 60's and can be introduced into asphalt mixtures through the wet process, by mixing crumb rubber with asphalt at a temperature which is sufficient to provoke physical and chemical changes that result in a modified binder. The properties of asphalt-rubber depend on: i) crumb rubber type; ii) processing method; iii) rubber concentration; iv) gradation of rubber particles; v) digestion time and digestion temperature. Thus these factors affect the physical properties such as viscosity, ring and ball softening point and elastic recovery [1].

According to Caltrans [2], asphalt rubber mixtures improve fatigue life, resistance to rutting and reflective cracking when compared to other mixtures. In California, the application of asphalt rubber gap-graded overlays has proved a reduction up to 50% the thickness of conventional overlays providing the same resistance to reflective cracking.

In this study, a laboratory research was conducted to evaluate the performance properties of asphalt rubber mixtures using a gap graded mixes through fatigue and permanent deformation tests. An identical study was carried out for a conventional mixture used as reference.

The mechanical results from the tests were compared by applying a pavement overlay design method that considers crack propagation from the existing pavement to the pavement overlay.

2. MATERIALS

2.1 Aggregates and mixture gradations

The materials used in this study included a crushed coarse aggregate (granite), crushed fine aggregate (granite) and mineral filler (limestone) that come from the northern of Portugal, with the following gradations:

- grade 1 - particles size 6 – 12 mm;
- grade 2 - particles size 4 – 10 mm;
- grade 3 - particles size ≤ 4 mm.

The aggregate laboratory tests confirmed that these aggregates have suitable properties for being used in pavement mixtures.

In this study, two types of aggregate gradations were used: dense graded and gap graded. Dense graded is a continuously graded aggregate blend typically used to produce hot mixture asphalt concrete pavements with conventional binders. In the gap graded mixture, the aggregate is not continuously graded for all size fractions, but it is

typically missing or low in some of the finer size fractions. Gap grading is used to promote stone-to-stone contact in hot-mixture asphalt concrete and it is similar to the gradations used in stone matrix asphalt, but with relatively low percentages passing through a 75μm (n° 200) sieve. This type of gradation is most frequently used to make rubberized asphalt concrete gap graded paving mixes [3].
The gap graded mixture used in this study was the Caltrans ARHM-GG mixture (asphalt rubber hot mixture gap graded), designed according to the Standard Special Provisions, SSP39-400 [4] and produced with asphalt rubber. The reference mixture, produced with conventional binder was the dense graded DNIT grade C specified by the *Departamento Nacional de Infra-Estrutura de Transportes DNIT 031/2006-ES* (in Portuguese). Table 1 presents the mixture gradations and Figure 1 shows the gradation curves of the mixtures.

Sieves	Percentage passing (%)	Sieves	Percentage passing (%)
	Conventional		Asphalt rubber
3/4"	100	3/4"	100
1/2"	97,5	1/2"	98,0
3/8"	85,5	3/8"	87,8
#4	51,5	#4	36,5
#10	36,0	#8	22,9
#40	19,0	#30	14,2
#80	11,6	#50	10,4
#200	6,1	#100	6,8
		#200	4,4

Table 1 : **Aggregate gradation of asphalt rubber and conventional mixtures**

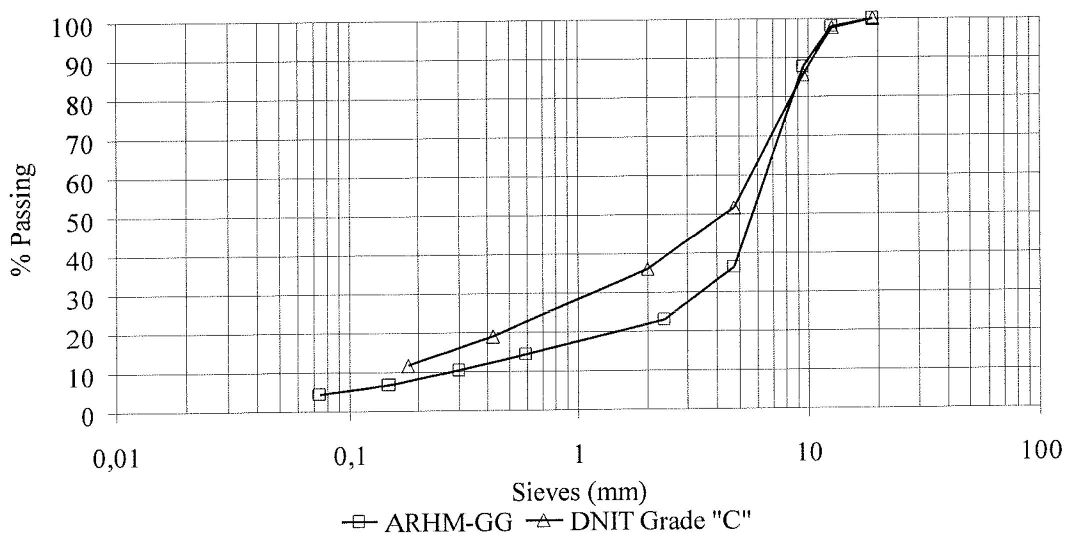
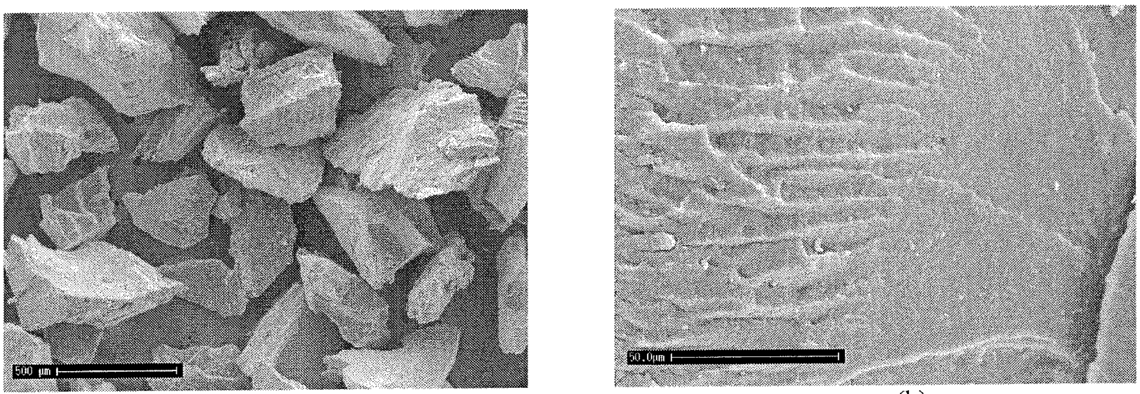


Figure 1 : **Aggregate grading curves**

2.2 Crumb rubber and asphalt binders

The crumb rubber modifier (CRM) was obtained by means of a cryogenic process and followed the ADOT requirements type B [5]. Cryogenic processing involves the use of liquid nitrogen or other materials/methods to freeze tire chips or rubber particles prior to size reduction. The surface of the rubber particles is glasslike, and has a lower surface area with particles of similar gradation [6]. Figure 2 presents the morphology of the cryogenic rubber used in this study, through the scanning electron microscopy (SEM), in (a) 50 times and in (b) 700 times, where the microestructure appearance appears to be angular with smooth cracked surface.
The conventional asphalt used to produce the reference mixture was a 50/70 penetration asphalt and the conventional asphalt used to produce the asphalt rubber was a 35/50 penetration asphalt.
The continuous blend describes the method of modifying asphalt cement with CRM produced from scrap tire rubber. This process requires to mix the CRM in hot asphalt cement (176°C to 226°C) and to submit the resulting blend to high temperatures (150°C to 218°C) during a certain period of time (digestion) to permit an interaction between rubber and asphalt [3].
The asphalt rubber (AR) produced by continuous blend process was made in laboratory with the following characteristics: 21% of crumb rubber; 90 minutes of digestion time; 180 °C of digestion temperature. The physical properties of the asphalts are presented in Table 2. The specifications for the asphalt rubber are given in brackets and follows ASTM D 6114 (1997).



(a) (b)

Figure 2 : **SEM of cryogenic crumb rubber**

Test	Standard	Asphalts binders		
		50/70	35/50	AR
Penetration (1/10 mm)* °C	ASTM D 5	51,5	33	26,0 (23-75)
Resilience (%)	ASTM D 5329	0	9	40 (14 min.)
Softening Point (°C)	ASTM D 36	51,5	52,7	65,0 (55 min.)
Viscosity** (cP) 175 °C	AASHTO TP 48	112	175	2826 (1500 min.)

*100g, 5s, 25; ** Brookfield viscometer, spindle 27, 20 rpm

Table 2 : **Characterization of asphalt binders**

2.3 Mixture design and specimens

The Marshall Method was used to determine the optimum binder content and the volumetric properties of each mixture. The optimum binder content and air voids are presented in Table 3.

Property	DNIT Grade "C"	ARHM-GG
Air voids (%)	4,0	6,0
Optimum binder content (%)	5,5	8,0

Table 3 : **Marshall properties**

After mixtures design, the necessary specimens for performing fatigue and permanent deformation tests were prepared. In the laboratory, the mixtures were compacted in slabs through the repeated passage of a cylinder with vibration over the asphalt mixture to achieve the apparent density of the asphalt hot mixtures defined in the design. Finally, the slabs of asphalt mixtures were sawed to provide cylindrical specimens for permanent deformation tests and prismatic specimens for fatigue tests.

3. EXPERIMENTAL

3.1 Dynamic modulus and fatigue

Fatigue resistance of asphalt mixtures is the ability to withstand repeated bending without fracture. Fatigue, a common way of distress in asphalt concrete pavements, manifests in the form of cracking from repeated traffic loading. The fatigue of asphalt mixture is influenced by several factors such as temperature, frequency of applied loads, mixture design and material properties [7]. One of the most common methods used to evaluate fatigue life in laboratory is the flexural bending beam test. The test apparatus used was a CS7800 Flexural Beam Device, as shown in Figure 3.
Flexural fatigue tests were conducted according to the AASHTO TP 8-94 (Standard Test Method for Determining the Fatigue Life of Compacted HMA Subjected to Repeated Flexural Bending).
The configuration applied was the four-point bending test in controlled strain. In controlled strain mode, the strain was kept constant and the stress decreased during the test. In general, controlled strain testing has been associated with thin pavements. The test procedure for all mixtures included two tests: (i) frequency sweep; (ii) fatigue. Prior the tests, the specimens were placed in an environmental chamber for approximately 2 hours to reach the test temperature.
All tests were carried out at 20 °C and at 10 Hz. For each mixture, nine specimens were tested at three strain levels, 200, 400 and 800 (E-6). The flexural beam device allows testing beam specimens up to dimensions of 50 mm by 63 mm by 380 mm. Fatigue failure was assumed to occur when the flexure stiffness reduces by 50 percent the initial value. Before the fatigue test, the frequency sweep test was conducted in the same equipment.

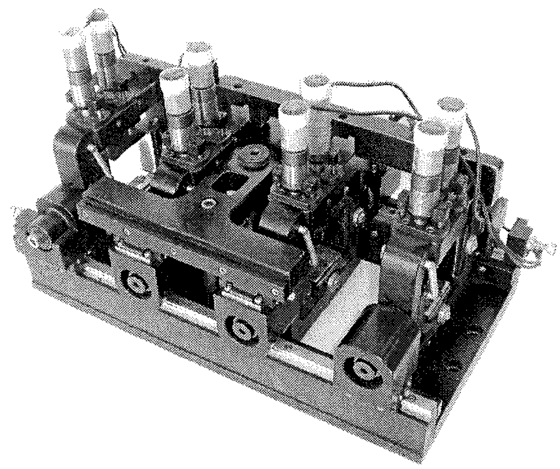


Figure 3 : **Flexural beam device**

For linear viscoelastic materials such as asphalt mixtures, the stress-strain relationship under a continuous sinusoidal loading is defined by a complex number called the complex modulus E*. The absolute value of the complex modulus |E*| is defined as the dynamic modulus. The E* test is generally performed in the laboratory at different temperature and frequency combinations.
The frequency sweep test measures the stiffness (dynamic modulus) of mixtures when subjected to different loading frequencies. The parameter phase angle which quantifies the elastic capacity of the material was also measured and it was calculated as a function of the time lag between the application of load (F) and the displacement (δ) produced in the specimen. In this study, seven frequencies were tested (10; 5; 2; 1; 0,5; 0,2; 0,1 Hz) in 100 cycles. The results of the tests are shown in Table 4.

Mixtures	Phase angle (°)	Dynamic modulus (MPa)
DNIT Grade "C"	19,6	6300
ARHM-GG	16,8	5190

Table 4 : **Marshall properties**

The values of phase angles of the ARHM-GG made with asphalt-rubber are lower than the conventional mixture prepared with conventional 50/70 pen asphalt, what indicates improvements on the elastic response of the asphalt rubber mixture in relation to the conventional one. Dense graded mixtures with conventional asphalt are stiffer than gap graded mixtures with asphalt rubber due to the high dynamic modulus. However, the low dynamic modulus of the ARHM-GG indicates that it has a lower stress to strain ratios than stiffer materials like DNIT Grade "C". The ARHM-GG has more elastic response to the same level of loading and consequently presents more flexibility to relieve stresses and to repair many of the cracks. Figure 4 presents the fatigue laws for both mixtures.

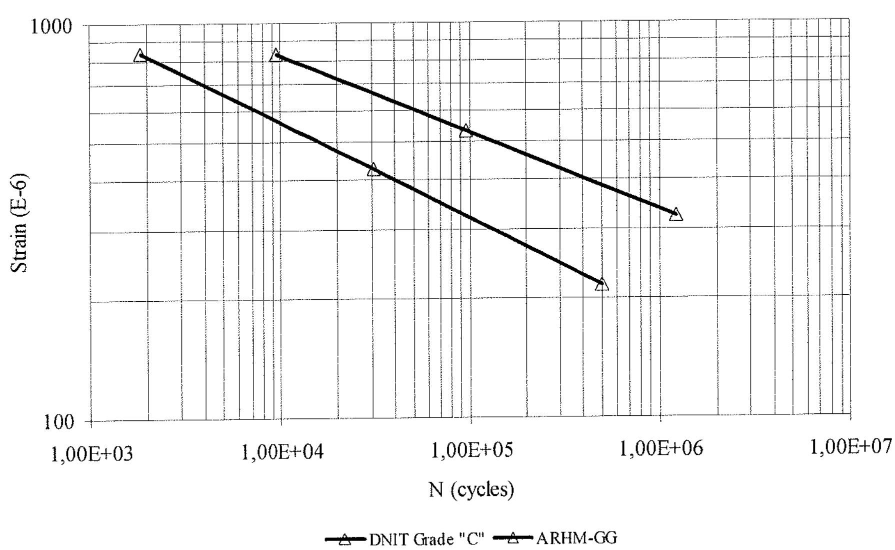


Figure 4 : **Fatigue laws**

The fatigue model used was the same proposed by Monismith et al (1971) [9], as presented in Equation 1:

$$N = a\left(\frac{1}{\varepsilon_t}\right)^b \quad (1)$$

where
N = number of repetitions to failure;
ε_t = tensile strain applied;
a and b = experimentally determined coefficients.
Each point of the fatigue law corresponds to three repetitions of the test for each three repetitions of strain levels applied.
The fatigue life curves (Figure 4) show that the ARHM-GG (mixture with asphalt rubber) presented longer fatigue life than the conventional mixture DNIT Grade "C".

3.2 Permanent deformation

Rutting, also known as permanent deformation, can be defined as the accumulation of small amounts of unrecoverable strains as a result of applied loading to a pavement. Permanent deformation is manifested in longitudinal depressions accompanied by upheavals to the side. The deformation pattern creates a loss of drainage capability of the pavement resulting in moisture damage. Further, the pavement becomes susceptible to fatigue cracking due to the structure retreating under the wheel path. Serious safety situations also arise as a result of the accumulation of water in the longitudinal depressions [10] [11].
The three constituents of asphalt mixtures (aggregate, binder, air voids) affect asphalt pavement rutting. Permanent deformation is caused by a combination of densification (decrease in volume and hence, increase in density) and shear deformation. For properly compacted pavements, shear deformations, caused primarily by large shear stresses in the upper portions of the asphalt-aggregate layers are dominant [10] [12].
Repetitive loading in shear is required in order to accurately measure, in laboratory, the influence of mixture composition on permanent deformation resistance. Because the rate at which permanent deformation accumulates with high temperatures, laboratory testing must be conducted at temperatures that best simulate the highest levels expected in the paving mixture in service [12]. In this study, the permanent deformation was evaluated by the RSST-CH (Repetitive Simple Shear Test at Constant Height) test and the mixtures specimens were tested at 60 °C, which is the temperature that corresponds to Brazil in summer pavement temperatures. Figure 5 presents the RSST-CH machine.

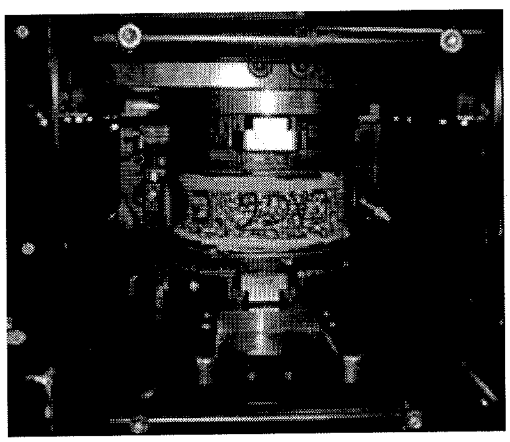


Figure 5 : RSST-CH machine

The RSST-CH test applies a repeated haversine shear stress of 1218 N to test specimens that have a diameter of 150 mm and are 50 mm high. During the test there is no change in volume (height of the specimen is maintained constant). The test specimens are glued to aluminium caps, top and bottom, using an epoxy resin. This process is made in an independent machine that ensures the parallelism between the two caps. The applied load has a duration of 0,1 seconds, with an unload time of 0,6 seconds. A vertical load applied to the sample during the test to ensure a constant height is obtained during the test. The test procedure followed by this test was AASHTO TP7-01, Test Procedure C. The shear stress is applied to the sample for 5000 loading cycles, or until the sample reaches 5% permanent shear strain. The RSCH-CH test is carried out until the specimens reaches the maximum plastic shear strain of 0,04545, which is equivalent to the limit value of 12,7 mm rut depth [12].
Table 5 presents the permanent deformation in terms of ESALs (Equivalent Single Axes Loads) for studied mixtures. The test data shown in Table 5 indicates that mixture ARHM-GG (with asphalt rubber) has a better performance than the conventional mixture.

Mixtures	ESALs to 12.5 mm rut depth
DNIT Grade "C"	7,18 E+5
ARHM-GG	8,14 E+6

Table 5 : Permanent deformation resistance

4. CRACK PROPAGATION

Cracks appear in flexible pavements primarily through either fatigue or reflective cracking mechanisms. Classical fatigue cracks are associated with weak areas in the pavement structure where heavy truck loads induce high tensile strains at the bottom of the asphalt layer. These strains initiate cracks that eventually propagate to the surface. The classical fatigue property of asphalt mixtures surface has been under evaluation for over 40 years. Great advances have been made in the equipment and understanding of the fatigue mechanism. Reflective cracks, on the other hand, are initiated by existing discrete subsurface defects such as joints, cracks, or stripping areas. The cause of reflective cracking can be either environmental or load associated. The reflective cracking mechanism has received less attention than classical fatigue studies. Reflective cracking is frequently a major performance issue as it is a major concern when selecting asphalt mixture overlays. It is well known that when reflective cracks propagate through the overlay, the infiltration of water can cause rapid deterioration of the underlying pavement structure and foundation.
Sousa et al. (2002) [13] developed a procedure to characterize the reflective cracking resistance of asphalt mixtures before they are applied on the existing cracked pavements. In this study, the mixtures were evaluated taking the cracking propagation phenomenon into account, by using the mechanistic-empirical based overlay design method for reflective cracking proposed by Sousa et al. (2002) [13].
The application of the design method requires the calculation of the von Mises strain deviator given by Equation 2:

$$\varepsilon_{VM}\ (1\times10^{-6}) = a \times [\text{Overlay thickness (m)}]^{b} \qquad (2)$$

where:
ε_{VM} = Von Mises strain;
a and b = statistical coefficients function of the pavement layer thickness and stiffness.

This model results from the application of the finite element method to a cracked pavement with an overlay layer on top of it as represented in Figure 6. The pavement is modeled by 4 layers, i.e., an overlay layer placed on a cracked layer, a granular layer, and the subgrade layer.

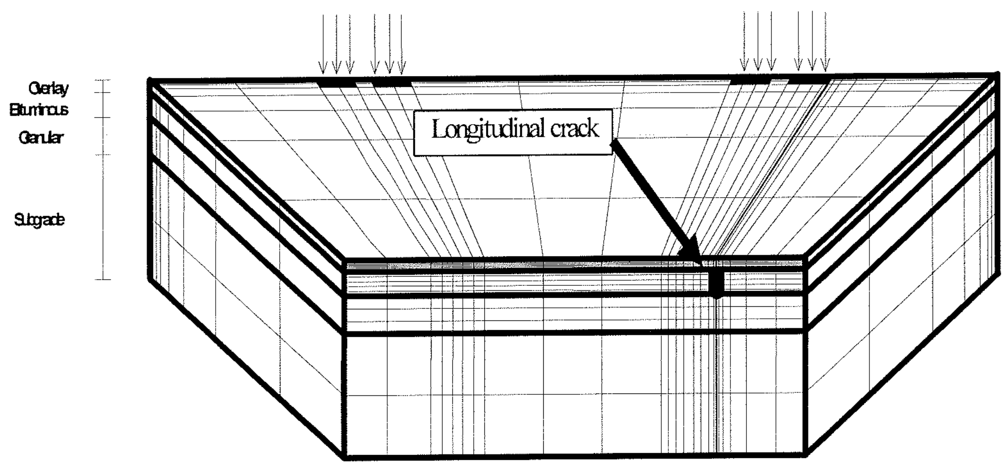


Figure 6 : 3D representation of finite element mesh

For the von Mises strain deviator calculation, a typical Brazilian pavement was defined, for medium traffic, as characterised in Table 6. The bituminous mixture properties to be included in the reflective cracking model (fatigue laws evaluated in four point bending tests and stiffness modulus) are defined in Table 7.

Layers	Thickness (m)	Stiffness (MPa)
asphalt	0,125	2000
granular	0,35	250
subgrade		100

Table 6 : Pavement used for cracking reflection evaluation

Mixtures	Fatigue law	Stiffness @ 10Hz, 20 °C (MPa)
DNIT Grade "C"	$2{,}15 \times 10^{15} \times (1/\varepsilon)^{4{,}124}$	6300
ARHM-GG	$9{,}81 \times 10^{18} \times (1/\varepsilon)^{5{,}138}$	5190

Table 7 : Fatigue laws and dynamic modulus used for cracking reflection evaluation

The application of the overlay design method needs the knowledge of the fatigue life law expressed in terms of Von Mises strain against the number of load cycles.
In flexural fatigue tests, the strain level applied during the tests can be correlated with the Von Mises strain by the following expression:

$$\varepsilon_{VM} = \varepsilon_1 (1 + \upsilon) \qquad (5)$$

where υ is the Poisson ratio.

Thus, the fatigue life laws can be expressed in terms of Von Mises strain if the interception coefficient of the fatigue law obtained during the laboratory test is multiplied by the Poisson coefficient.
The application of the overlay design method for 10% cracking at the end of design life and for a climate environment characterized by a maximum air temperature of 42°C, a mean annual air temperature given by the Shell method of 23 °C and a minimum air temperature of -4 °C allowed obtaining the overlay life prediction given in Figure 7.

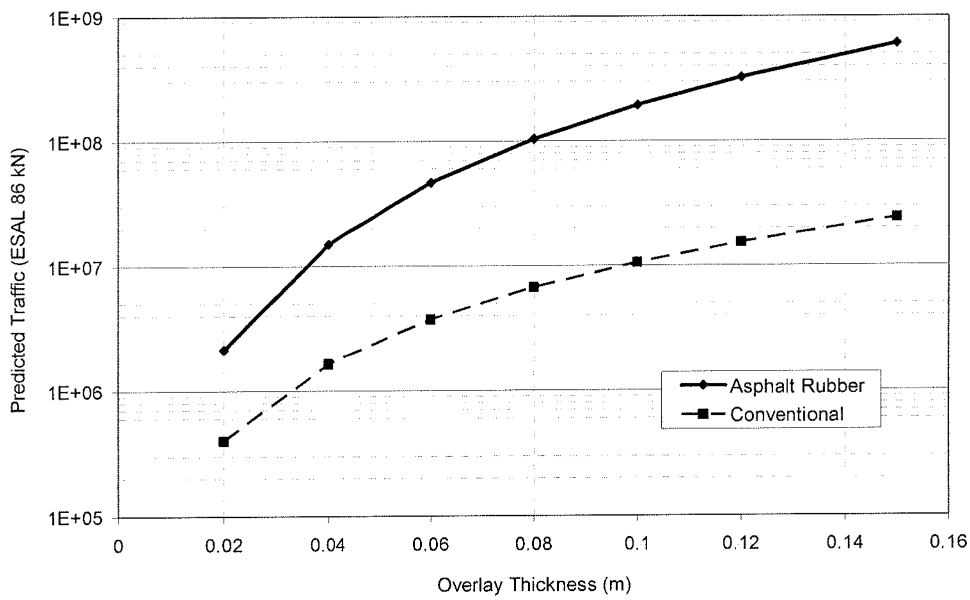


Figure 7 : Overlay life prediction due the reflective cracking

The analysis of the predicted overlay life shows that the asphalt rubber mixture exhibits a higher reflective cracking fatigue life than the conventional mixture. The difference between the studied mixtures is more significant for higher traffic levels where the conventional mixture requires to be double the thickness than that of asphalt rubber mixtures. Considering the same overlay thickness, asphalt rubber mixtures nearly bear ten times more traffic than conventional mixtures. As the overlay thickness increases this difference increases as well. This can be observed by the slope of the line in Figure 7.

5. CONCLUSIONS

This study has intended to establish a comparison between asphalt rubber mixtures and conventional mixtures usually used for pavement rehabilitation.
The results of asphalt modification by crumb rubber allowed to conclude that the addition of crumb rubber in conventional asphalt produces an increase of the Brookfield viscosity, the softening point and the resilience, creating a modified binder with characteristics different from the asphalt base.
The performance evaluation of the two mixtures analysed in this study was characterized in terms of fatigue life and permanent deformation resistance. The dynamic modulus was also evaluated. The crack propagation resistance was estimated by an overlay design method that uses the Von Mises strain and fatigue results.

The stiffness results allowed concluding that asphalt rubber presents a lower dynamic modulus than conventional mixtures what demonstrates there exist an elastic response and more flexibility to support stresses originated by the movements in the zone above the cracks.
When the modified binder, i.e. asphalt rubber, is used to produce an asphalt mixture, in comparison with a conventional one, the new characteristics influence and improve the results of the fatigue life, permanent deformation and crack propagation of pavements.
The fatigue and the permanent deformation tests showed that the mixture ARHM-GG has a more adequate performance than the conventional mixture DNIT Grade "C".
In terms of reflective cracking propagation, the results show that the asphalt rubber mixture exhibits higher reflective cracking fatigue life than the conventional mixture. The difference between the studied mixtures is more significant for higher traffic levels where the conventional mixture requires more than two times the thickness than the asphalt rubber mixture. Considering the same overlay thickness, the asphalt rubber mixture bears approximately ten times more traffic than the conventional mixture. If the overlay thickness increases this difference will also increase.

6. ACKNOWLEDGEMENTS

The fourth author was supported by the Programme Alban, the European Union Programme of High Level Scholarships for Latin America, scholarship n° E04D040507BR between 2004 and 2006. Current, the fourth author is supported by CNPQ (Conselho Nacional de Desenvolvimento Científico e Tecnológico).

REFERENCES

[1] Heitzman, M.A. "State of the Practice - Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier". Federal Highway Administration, Report n° FHWA-SA 92022. USA, 1992.
[2] Caltrans, " Maintenance Technical Advisory Guide (TAG)", Caltrans, State of California Department of Transportation, Sacramento, California, USA, 2003.
[3] Caltrans, "Use of Scrap Tire Rubber State of the technology and Best Practices". State of California Department of Transportation Materials Engineering and Testing Services Office of Flexible Pavement Materials. Sacramento, Califórnia, USA, 2005.
[4] Caltrans, "Standard Special Provisions", State of California Department of Transportation, Sacramento, California, USA, 2003.
[5] ADOT, "ADOT Construction Manual", Arizona Department of Transportation, Intermodal Transportation Division, Arizona, USA, 2005.
[6] Baker, T.E., Allen, T.M., Jenkins, D.V., Mooney, T., Pierce, L.M., Christie, R.A. and Weston, J.T., "Evaluation of the Use of Scrap Tires in Transportation Related Applications in the State of Washington", Washington State Department of Transportation, Washington, D.C.,USA, 2003.
[7] Pereira, P.A.A., Pais, J.C. and Sousa, J.B., "Comparison Between Laboratorial and Fields Bituminous Mixes". Mechanical Tests for Bituminous Materials. RILEM, Lyon, 1997.
[8] Monismith, C.L., Epps, J.A., Kasianchuk, D.A. and McLean, D.B., "Asphalt Mixture Behaviour in Repeated Flexure". Report TE 70-5. University of Clifornia, Berkeley, California, USA, 1971.
[9] Maupin Jr, G.W. and Mokarem, D.W. "Investigation of AASHTO Rut Test Procedure Using the Asphalt Pavement Analyzer". Final Report VTRC 07-R11. Virginia Transportation Research Council. Virginia, USA, 2006.
[10] Panoskaltsis, V.P, Bahuguna, S. and Papoulia, K. D., "A Model Explaining and Predicting the Permanent Deformations of Asphalt Pavements". 16th ASCE Engineering Mechanics Conference. University of Washington, Seatle, USA, 2003.
[11] Sousa, J.B., Solaimanian, M. and Weissman, S.L., "Development and Use of the Repeated Shear Test (Constant Heigh): Na Optional Superpave Mix Design Tool", Strategic Highway Research Program, SHRP-A-698, Washington, DC, 1994.
[12] Zhou F. and Scullion, T. "Overlay Tester: A Rapid Performance Related Crack Resistance Test". FHWA/TX-05/0-4467-2. Texas Department of Transportation. Research and Technology Implementation Office. Austin, Texas, USA, 2005.
[13] Sousa J., Pais J.C., Saim R., Way G. and Stubstad R., "Development of a Mechanistic-Empirical Based Overlay Design Method for Reflective Cracking". Transportation Research Board, USA, 2002.