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THE USE OF ASPHALT RUBBER MIXTURES TO IMPROVE PAVEMENT OVERLAYS

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ABSTRACT

Asphalt modified with crumb rubber has been used to produce asphalt rubber mixtures for pavement overlays subjected to heavy loads and high temperatures. 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. 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. Besides the use of rubber as an additive in conventional asphalts and the use of asphalt rubber is an attractive from the standpoint of environmental preservation.

Keywords. Asphalt rubber, fatigue, permanent deformation, continuous blend, asphalt.

1. INTRODUCTION

Pavement overlay consists of placing the required thickness of asphalt mix on 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 aim an overlay that will able to return the old pavement to a high level of serviceability and provide the necessary structural strength for the project life, it is necessary to design a desirable mix.

An asphalt rubber pavement overlay represents a viable rehabilitation strategy. Rubber from waste tires has been used in asphalt mixes since the late 60's and can be introduced into asphalt mixes through the wet process, by reacting crumb rubber with asphalt at temperatures sufficient to cause physical and chemical changes that result in a modified binder. The factors affecting the properties of asphalt-rubber are: crumb rubber type; processing method; rubber concentration; gradation of rubber particles; digestion time and digestion temperature. These factors affect the physical properties like viscosity, ring and ball softening point and elastic recovery (Heitzman, 1992).

According to Caltrans (Caltrans$_A$, 2003), the asphalt rubber binder improves fatigue life, resistance to rutting, and reflective cracking when compared to other binders. In California, asphalt rubber gap-graded overlays may be reduced up to 50% the thickness of conventional overlays and still provide the same resistance to reflective cracking.

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

2. MATERIALS

2.1 Aggregates and mix 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: (i) grade 1 – particles size 6 – 12 mm; (ii) grade 2 – particles size 4 – 10 mm; (iii) grade 3 – particles size ≤ 4 mm.

The aggregate laboratory tests, confirmed that these aggregates have suitable properties for use in pavement mixes.

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 make hot mix asphalt concrete pavements with conventional binders. In the gap graded gradation, the aggregate that is not continuously graded for all size fractions, but is typically missing or low on some of the finer size fractions. Gap grading is used to promote stone-to-stone contact in hot-mix asphalt concrete and is similar to the gradations used in stone matrix asphalt, but with relatively low percentages passing the 75µm (nº 200) sieve. This type of gradation is most frequently used to make rubberized asphalt concrete gap graded paving mixes (Caltrans, 2005).

The gap graded gradation used in this study was Caltrans ARHM-GG mix (asphalt rubber hot mix gap graded), designed according to the Standard Special Provisions, SSP39-400 (Caltrans$_B$, 2003) and produced with asphalt rubber. The reference mix, produced with conventional binder was dense graded DNIT grade "C" specified by *Departamento Nacional de Infra-Estrutura de Transportes* DNIT 031/2006-ES (in Portuguese). The Figure 1 shows the gradation curves of the mixes and the Table 1 presents the mix gradations.

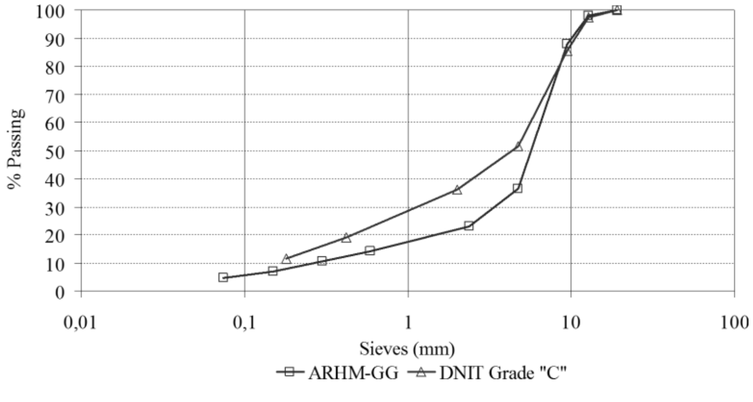


Figure 1. Aggregate grading curves

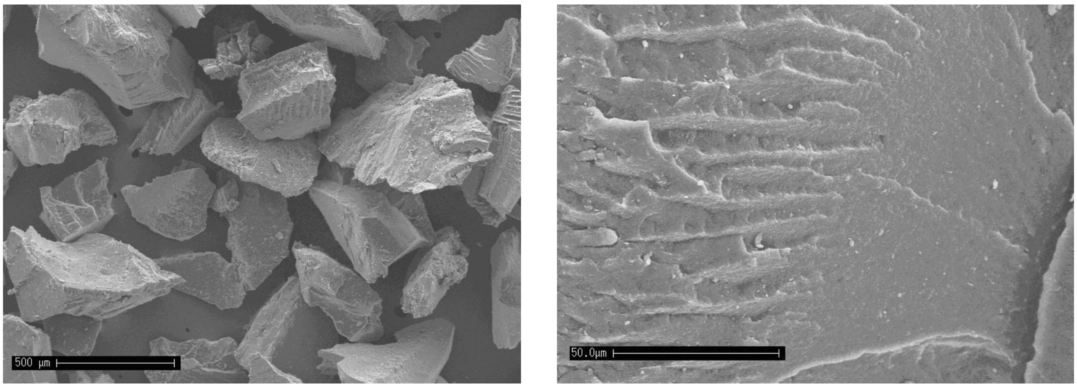
Table 1. Aggregates proportions and mixes compositions

Mixes	Grade 1 (%)	Grade 2 (%)	Grade 3 (%)	Filler (%)
ARHM-GG	21,0	56,0	20,0	3,0
DNIT grade C	27,0	30,0	40,0	3,0

2.2 Crumb rubber and asphalts

The crumb rubber modifier (CRM) was obtained from cryogenic process and followed the ADOT requirements type B (ADOT, 2005). Cryogenic processing refers to 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 sizes of similar gradation (Baker *et al*., 2003).

The Figure 1 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 microstructures appearance looks to be angular with smooth cracked surface.



(a) (b)

Figure 2. SEM of cryogenic crumb rubber

The conventional asphalt used to produce the reference mix was CAP-50/70, classified by penetration and the conventional asphalt used the base to make the asphalt rubber was PEN 35/50, classified by penetration, as well.

The wet process continuous blend describes the method of modifying asphalt cement with CRM produced from scrap tire rubber. This process requires thorough mixing of the CRM in hot asphalt cement (176ºC to 226ºC) and holding the resulting blend at elevated temperatures (150ºC to 218ºC) for a designated period of time (digestion) to permit an interaction between the rubber and asphalt (Caltrans, 2005).

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 ºC of digestion temperature. The physical properties of the asphalts are presents in Table 2. The specifications are given in brackets, conventional asphalt CAP 50/70 followed DNIT 095/96-EM, conventional asphalt PEN 35/50 followed *Laboratório Nacional de Engenharia Civil* (LNEC 1997 in Portuguese) and the asphalt rubber followed ASTM D 6114 (1997).

Table 2. Characterization of asphalt binders

Test	Standard	Asphalts binders		
		CAP-50/70	**PEN 35/50**	**AR**
Penetration (1/10 mm)* ºC	ASTM D 5	51,5 (50-70)	33 (35-50)	26 (23-75)
Resilience (%)	ASTM D 5329	0	9	40 (14 min.)
Softening Point (ºC)	ASTM D 36	51,5 (50 min.)	52,7 (50-78)	65 (55 min.)
Viscosity** (cP) 175 ºC	AASHTO TP 48	112 (57-285)	175	2826 (1500 min.)

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

2.3 Mixes design and specimens

Marshall Method was used to determine the optimum binder content and the volumetric properties of each mix. The optimum binder content and air voids are presented in Table 3. After mixes design, the specimens to fatigue and permanent deformation tests were prepared. In the laboratory, the mixes were compacted in slabs through the repeated passage of a cylinder with vibration over the bituminous mixture to achieve the apparent density of the asphalt hot mixes defined in the design. Finally, the slabs of bituminous mixes were sawed to produce cylindrical specimens for permanent deformation tests and prismatic specimens for fatigue tests.

Table 3. Marshall properties

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

3. EXPERIMENTAL

3.1 Dynamic modulus and fatigue

The fatigue resistance of an asphalt mix is its ability to withstand repeated bending without fracture. Fatigue, a common form of distress in asphalt concrete pavement, manifests itself in the form of cracking from repeated traffic loading. The fatigue of asphalt mix is influenced by several factors such as temperature, frequency of applied loads, mixture design and material properties (Pereira *et al.*, 1997). 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 showed 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 employed was the four-point bending test in controlled strain. In controlled strain mode, the strain was kept constant and the stress decreases during the test. In general, controlled strain testing has been associated with thin pavements. The test procedure for all mixes included two tests: (i) frequency sweep; (ii) fatigue. Prior the tests, the specimens were placed in an environmental chamber for 2 hours at least to reach the test temperature.

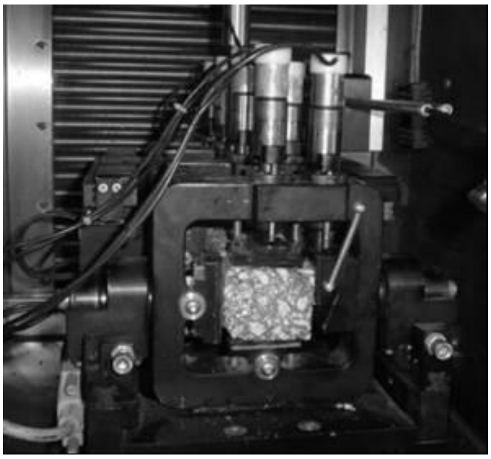


Figure 3. Flexural beam device

All tests were carried out at 20 ºC and at 10 Hz. For each mix, were tested nine specimens 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 to 50 percent of the initial value. Before the fatigue test, the frequency sweep test was conducted in the same machine.

For linear viscoelastic materials such as asphalt mixes, 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, in general, performed in the laboratory at different temperatures and frequencies combination.

The frequency sweep test measures the stiffness (dynamic modulus) of mixes when subjected to different loading frequencies. The parameter phase angle which measure the elastic capacity of the material, was measure as well and 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.

Table 4. Phase angle and dynamic modulus

Mixes	Phase angle (º)	Dynamic modulus (MPa)
DNIT Grade "C"	19,61	6300
ARHM-GG	16,82	5192

The values of phase angles of the ARHM-GG made with asphalt-rubber are lower than the conventional mixture prepared with conventional CAP-50/70, which indicates improvements on the elastic response of the asphalt rubber mix in relation to conventional one. Dense graded mix with conventional asphalt is stiffer than the gap graded mix with asphalt rubber due to the high dynamic modulus. However, the low dynamic modulus of the ARHM-GG means that it has 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 heal many of the cracks. The Figure 4 presents the fatigue laws for the two mixes.

The fatigue model used was the same proposed by Monismith *et al.* (1971), (Maupin & Mokarem, 2006), as presents in Equation 1:

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

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) shows that the ARHM-GG (mix with asphalt rubber) presented longer fatigue life than the conventional mix DNIT Grade “C”.

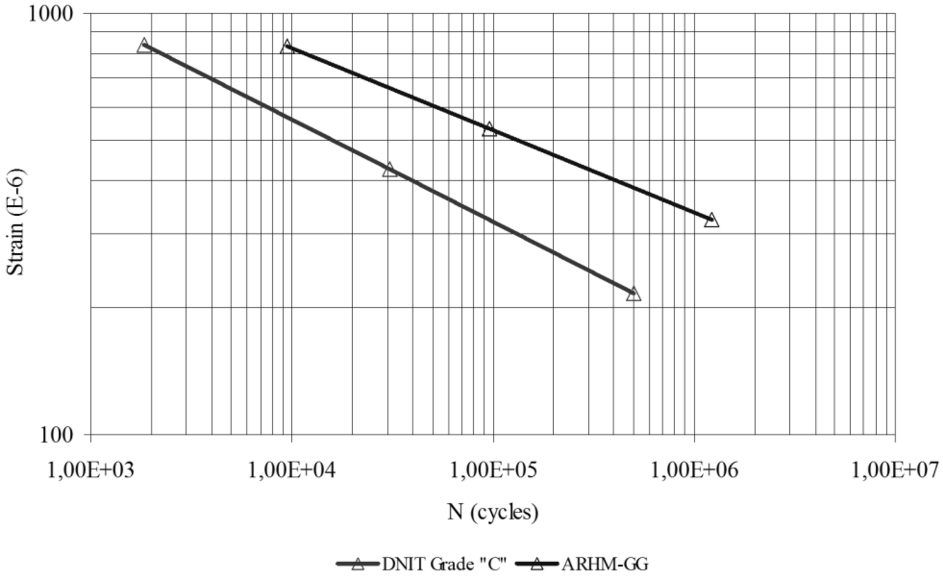


Figure 4. Fatigue laws

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 manifest 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 gets susceptible to fatigue cracking as a result of thinning of the structure under the wheel path. Serious safety situation also arises as a result of accumulation of water in the longitudinal depressions (Panoskaltsis *et al.*, 2003); (Sousa et al., 1994).

The three constituents of asphalt mix (aggregate, binder, air voids) have an effect on rutting of an asphalt mix pavement. Permanente 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 (Panoskaltsis *et al.*, 2003); (Zhou & Scullion, 2005).

Repetitive loading in shear is required in order to accurately measure, in the laboratory, the influence of mixture composition on permanent deformation resistance. Because the rate at which permanent deformation accumulates with higher temperatures, laboratory testing must be conducted at temperatures simulating the highest levels expected in the paving mixture in service (Sousa *et al.*, 2002). In this study, the permanent deformation was evaluated by the RSST-CH (Repetitive Simple Shear Test at Constant Height) test and the mixes specimens were tested at 60 ºC, which is the temperature that corresponds to Brazil in summer pavement temperatures. Figure 5 presents the RSST-CH machine.

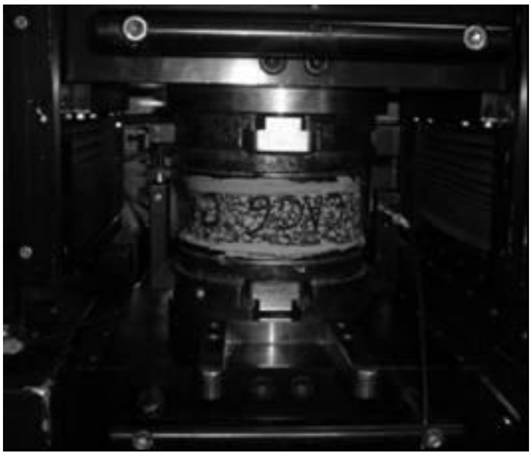


Figure 5. RSST-CH machine

The RSST-CH test applies a repeated haversine shear stress of 1218 N to test specimens that has the dimensions of 150 mm in diameter and 50 mm in height. 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 is applied to the sample during the test to ensure a constant height is obtained during the test. The test procedure followed for 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 (Sousa *et al.*, 1994).

Figure 6 presents the permanent deformation in terms of ESALs (Equivalent Single Axes Loads) for studied mixes. The test data shown in Figure 6 indicates that mix ARHM-GG (with asphalt rubber) has better performance than the conventional mix.

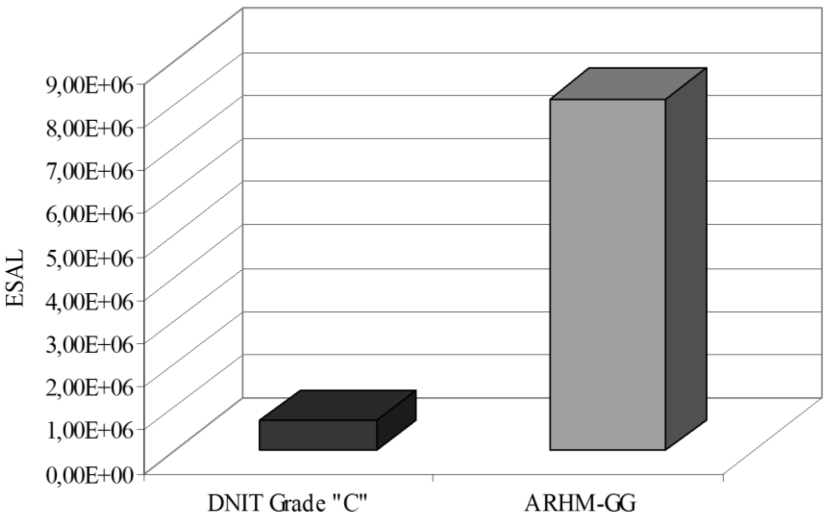


Figure 6. Permanent deformation results

5. CONCLUSIONS

Based on the results of evaluation and analysis, conclusions and recommendations of this study are described as the following:
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 different characteristics from the asphalt base.
In this study were evaluated the conventional dense graded mix DNIT Grade "C" and the gap graded mix ARHM-GG with asphalt rubber produced in wet process (21% of crumb rubber). These mixes were evaluated through the fatigue and permanent deformation tests.
When he modified binder, asphalt rubber, is used to produce an asphalt mix, in comparison with a conventional one, the new characteristics influence and improve the results of the fatigue life, permanent deformation and crack propagation.
The fatigue and the permanent deformation tests showed that the mix ARHM-GG has the better performance than the conventional mix DNIT Grade "C".
The introduction of used rubber tires in asphalt showed carry on higher modifications that result in a considerable increase permanent deformation and fatigue life of the asphalt rubber mix compared to the conventional one. This alternative, also represents an improvement in the mechanical capability of the mixtures was shown to be ecologically correct, since it removes the nature of the used tire.

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REFERENCES

ADOT (2005). *ADOT Construction Manual*, Arizona Department of Transportation, Intermodal Transportation Division, Arizona, USA.

Baker, T. E., Allen, T. M., Jenkins, D. V., Mooney, T., Pierce, L. M., Christie, R. A. and Weston, J. T. (2003). "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.

Caltrans_A (2003). *Caltrans Maintenace Technical Advisory Gide (TAG)*. California Department of Transportation, Sacramento, California, USA.

Caltrans_B (2003). *Standard Special Provisions*. State of California Department of Transportation, Sacramento, California, USA.

Caltrans (2005). *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.

Heitzman, M. A. (1992). "State of the Practice - Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier". Federal Highway Administration, Report nº FHWA-SA 92022. USA.

Maupin Jr, G. W. and Mokarem, D. W. (2006). "Investigation of AASHTO Rut Test Procedure Using the Asphalt Pavement Analyzer". Final Report VTRC 07-R11. Virginia Transportation Research Council. Virginia, USA.

Monismith, C. L., Epps, J. A., Kasianchuk, D. A. and McLean, D. B. (1971). "Asphalt Mixture Behaviour in Repeated Flexure". Report TE 70-5. University of Clifornia, Berkeley, California, USA.

Panoskaltsis, V. P, Bahuguna, S. and Papoulia, K. D. (2003). "A Model Explaining and Predicting the Permanent Deformations of Asphalt Pavements". 16th ASCE Engineering Mechanics Conference. University of Washington, Seatle, USA.

Pereira, P. A. A., Pais, J. C. and Sousa, J. B. (1997). "Comparison Between Laboratorial and Fields Bituminous Mixes". Mechanical Tests for Bituminous Materials. RILEM.

Sousa, J. B., Solaimanian, M. and Weissman, S. L. (1994), "Development and Use of the Repeated Shear Test (Constant Heigh): Na Optional Superpave Mix Design Tool", Strategic Highway Research Program, SHRP-A-698, Washington, D.C.

Sousa J. B., Pais J. C., Saim R., Way G. and Stubstad R. (2002). "Development of a Mechanistic-Empirical Based Overlay Design Method for Reflective Cracking". Transportation Research Board, USA, 2002.

Zhou F. and Scullion, T. (2005). "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.