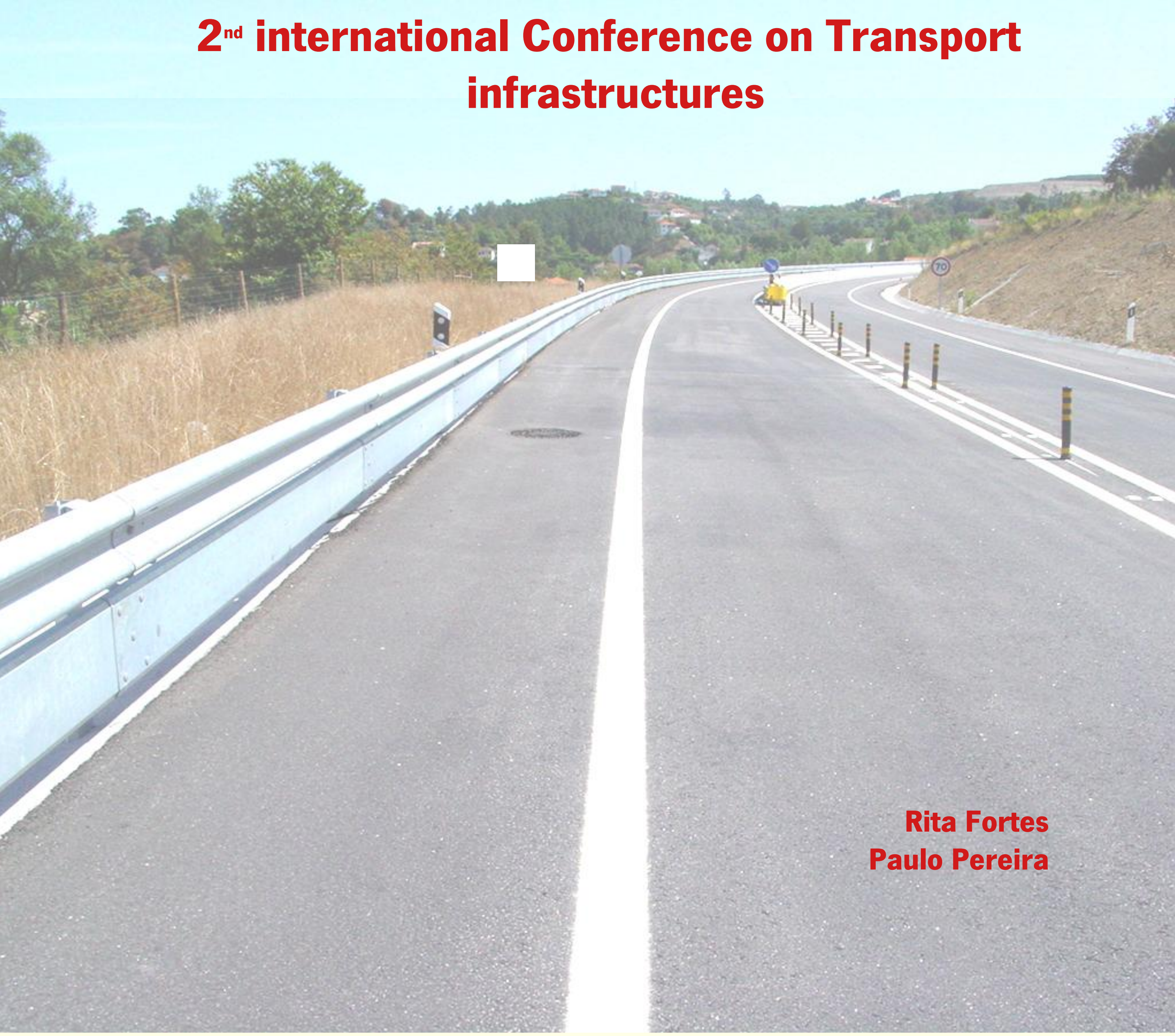
2nd international Conference on Transport infrastructures



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PREFACE

A suitable transport infrastructure has always been essential for the mobility of the persons and goods all over the world since remote ages.

Most of the transport infrastructures have been developed under national policy premises. There is the need to establish a single, multimodal system integrating land, sea and air transport connections which ensure the sustainability of our transport networks into the future. Environmental protection requirements are also the key to development sustainability and should not be left apart.

The worldwide awareness of the sustainability of life and nature is indicative of an important role that civil infrastructures play in guaranteeing a sustainable life quality. Once an infrastructure is constructed its life-cycle demands a great effort in terms of maintenance and rehabilitation, in order not to jeopardize the initial investment in infrastructure assets and not to degrade surrounding and global environment.

Thus, the iCTi series has been implemented with the support of a permanent organization, a technical and learned society – iSMARTi – with the aim of disseminating the most recent research in the themes approached in this international conference.

After its first Conference in China, this second ICTI welcomes you in São Paulo, Brazil.

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Use of Tire Rubber to Improve Fatigue Performance of Asphalt Mixtures

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ABSTRACT: The accelerated failure of pavements is one of the main problems in Brazilian roads resulting from fatigue cracking due to the repeated application of traffic induced stresses. The incorporation of crumb rubber from waste tires in asphalt, named asphalt rubber, is a method which has been used in several countries to improve the properties of asphalt pavement mixtures and, at the same time, has been a ecologically alternative to deal with the proper disposal of waste tires. This paper describes the results obtained from a laboratory investigation that was undertaken to evaluate the fatigue performance of asphalt rubber mixtures produced by using the wet process with asphalt rubber binder from the continuous and terminal blend. The results were compared to the ones obtained from a reference mixture produced with conventional asphalt typically used in pavement rehabilitation. The laboratory performance of these mixtures was evaluated in terms of fatigue through four-point bending fatigue test. The dynamic mechanical properties, namely the stiffness modulus and fatigue resistance of rectangular beam specimens were evaluated for both types of mixture. The results showed that the asphalt rubber mixtures produced with Brazilian materials and asphalt rubber from the terminal blend system presented the largest fatigue in comparison with the typical mixtures used for pavement rehabilitation. This research allowed defining alternative mixtures which may improve the performance of Brazilian pavements. Correlations between fatigue performance and asphalt rubber characterization in terms of penetration, softening point, resilience and apparent viscosity, were established indicating that the fatigue performance can be predicted through the softening point of the binder.

KEY WORDS: Asphalt Rubber; Wet process; Fatigue.

1. INTRODUCTION

As in other developed countries in the world, Brazil has to deal not only with problems caused by roads subject to failure, but also with waste tires disposal. The main distress observed in Brazilians roads is the fatigue cracking, which results from the repeated application of traffic induced stresses. The incorporation of crumb rubber from waste tires in asphalt, named asphalt rubber, has been used in several countries around the world to improve the properties of the asphalt mixtures being at the same time an ecological alternative to re-use waste tires.

The major transportation mode for people and goods in Brazil is based on roads due to the fact that distances can range up to 4000 km. However, the quality of most roads is poor and a significant part of the Brazilian highways lack adequate driving conditions. Therefore pavements need new materials which may support high loads and a considerable traffic volume without reaching premature failure.

In Brazil, one of the methods to solve the problem of waste tires is to grind them and incorporate them into asphalt to produce the asphalt rubber that is used in high performance asphalt mixtures. The use of recycled tire rubber in asphalt may be carried out through Wet process, which consists of dissolving crumb rubber in the asphalt as a binder modifier.

In this study, four asphalt rubber mixtures were evaluated through fatigue tests (flexural four point bending). A conventional mixture was tested to be used as a reference mixture. Two aggregate gradations were chosen: a gap graded for asphalt rubber mixtures; a dense graded for the conventional mixture. In order to produce asphalt rubber, the conventional asphalt used in the conventional mixture was a 50/70 pen asphalt, which is the most common category applied in asphalt pavement mixtures in the South of Brazil. The asphalt rubbers were produced by the continuous blend process (prepared in laboratory) and the terminal blend process (made in a refinery).

2. FATIGUE APROACH

Asphalt mixtures in road pavements are subjected to a short term load each time a vehicle passes. This causes micro damages that result in a loss of rigidity of the material, what may lead, in the long term, to failure (Di Benedetto *et al.*, 2003). Under the action of repeated vehicular loading, deterioration of the asphalt concrete materials in pavements, caused by the accumulation and growth of micro and macro cracks, gradually takes place (Suo & Wongl, 2009). Thus, fatigue cracking is one of the major modes of distress in flexible pavements along with rutting and thermal cracking.

Fatigue is a significant distress as fatigue cracking propagates through the entire asphalt mixture layer, which then allows water infiltration into the unbound layers (Priest, 2005). This causes accelerated surface and structural deterioration as well as pumping of the unbound materials and rutting. The model definition of fatigue theory states that fatigue cracking initiates at the bottom of the flexible layer due to repeated and excessive loading and that it is associated with the tensile strains at the bottom of the asphalt mixture layer (Romero *et al.*, 2000).

In spite of the fact that fatigue cracking involves tensile failure at stress or strain levels lesser than the static strength of the material, the asphalt mixture stiffness, temperature variations and loading frequency need to be taken into account in pavement design.

Fatigue cracking is the primary pavement distress at intermediate service temperatures (Roberts *et al.*, 1996). Pavement fatigue cracking is considered a strain controlled distress in thin pavement layers (up to 5 cm thick) because deformations in the asphalt layers are typically the result of a poor subsurface layer support and not so much of the effect of decreases in pavement stiffness (Huang, 1993).

Pavement fatigue cracking is considered a stress-controlled distress in thick pavement layers (greater than 15 cm), as the pavement is the main load-carrying constituent. A combination of both stress controlled and strain controlled distresses exists with intermediate thickness asphalt mixture pavements.

3. LABORATORY STIFFNESS MODULUS AND FATIGUE TEST

In the laboratory, fatigue life is typically assessed by repeated load bending tests. The configuration employed in this study to evaluate the fatigue resistance of the mixtures was the four-point bending test in controlled strain, presented in Figure 1. 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).

A servo electric hydraulic controlled testing system equipped with an automatic data measuring system applied the sinusoidal input strain waveform. Loading data were measured through the load cell and flexural deflections were recorded through a single linear differential variable transducer (LVDT) attached to the centre of the specimen. During the test, load and flexural deformation data were captured electronically every 0.002 s. Actual loading of the specimen was transmitted by the bending beam device, to which the beam specimen was firmly clamped.

The bending beam fatigue test consists of applying a repeated constant vertical strain to a beam specimen in flexural tension mode until failure or up to a specified number of load cycles. In this study, the test was performed in strain controlled mode of loading applying a input strain sinusoidal waveform at a frequency of 10 Hz without any rest period.

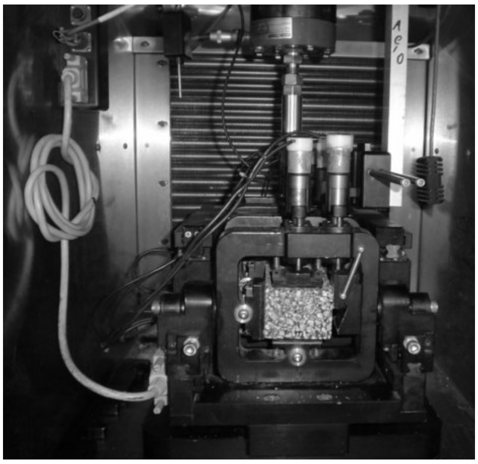

Figure 1: Fatigue test equipment (Axial Testing System and Flexural Beam Device)

3.1. Stiffness modulus test

The frequency sweep test measures the stiffness (dynamic modulus) and the phase angle of a mixture when subjected to different loading frequencies. This test was performed in the same beam used for the fatigue test prior the fatigue test. All frequency sweep tests of this study were executed at a strain level of 100 microstrains, at seven frequencies: 10, 5, 2, 1, 0.5, 0.2, 0.1 Hz and at the test temperature of 20 ºC. To minimize the damage of the beam, only 100 cycles were applied for the first three frequencies and 10 cycles for the last four ones. Prior to testing, the specimens were placed in the environmental chamber for 2 hours at the test temperature.

3.2. Fatigue test

The simple flexural four-point test followed AASHTO TP8/94. In this test, samples of asphalt mixtures were cut in to beams with the following dimensions: 50 mm x 63 mm x 380 mm. The test was conducted at three strain levels of approximately 200, 400 and 800 microstrains, consistent with the AASHTO TP8-94 test protocol, in a controlled chamber at a temperature of 20±0.5 °C. The specimens were previously conditioned for 2 hours.

Failure criteria are defined as the point at which the specimen flexural stiffness is reduced to 50% of the initial flexural stiffness (Di Benedetto *et al.,* 2003). This initial stiffness is generally defined as the specimen flexural stiffness measured at the 100th load cycle.

The selected AASHTO TP8/94 standard used in this study utilizes the flexural bending beam fatigue test (four-point loading) and considers bottom-up cracking to determine an empirical fatigue relationship of the simple power form (Monismith *et al.*, 1971) shown as:

$$N = a(1/\varepsilon_t)^b \qquad (1)$$

where: N = number of repetitions until failure; ε_t = tensile strain applied; a and b = experimentally determined coefficients.

The design strain at which the pavement fatigue life must be estimated using the empirical fatigue relationship developed based on laboratory test results is often computed using a simple multilayer elastic theory.

4. ASPHALT RUBBER

One of the main problems, that mankind faces this century, is related that waste tires disposal management. In the world, large amounts of rubber are used in tires for airplanes, trucks and cars. Crumb rubber modifier (CRM), is the denomination given to the material derived from reducing waste tires into uniform rubber granules. For road pavement applications the particles are normally finer than 4.75 mm (sieve nº 4).

The application of crumb rubber in asphalt mixtures intend to improve the properties of asphalt by reducing the binder's inherent temperature susceptibility. During the interaction with asphalt, the crumb rubber particles absorb a portion of the oils in asphalt and the particles swell; therefore increasing the viscosity and stiffness of the asphalt rubber (Lee *et al.*, 2008).

Processing waste tires into CRM can be accomplished through two main types of grinding: ambient (at ambient temperature) and cryogenic (uses liquid nitrogen).

There are two main processes for applying CRM into asphalt mixtures: the dry and the wet process. In the dry process, crumb rubber is added to the aggregate, as a fine aggregate, before the asphalt binder is added to the mixture. In the wet process, asphalt cement is pre-blended with the rubber at high temperatures (177 to 210 ºC) and under specific blending conditions. The final product is called asphalt rubber, which sees its binder properties improved by the addition of the rubber (Heitzman, 1992).

The blending methods in the wet process are commonly divided into two systems: continuous blend that describes those wet process technologies that include a continuous production system and, terminal blend, produced by blending crumb rubber and other additives with asphalt at the asphalt terminal. Nowadays, in Brazil, the terminal blend asphalt rubbers are produced, manly with two rubber concentrations, 15 and 20%.

5. EXPERIMENTAL RESULTS

5.1. Properties of the aggregates

The aggregates used in this study included a crushed coarse aggregate (granite), crushed fine aggregate (granite) and mineral filler (limestone) that come from the north of Portugal, with the following gradations: grade 1 with particles from 6 to 12 mm; grade 2 with particles from 4 to 10 mm and grade 3 with particles ≤ 4 mm. Material properties for the coarse and fine aggregates, listed in Tables 1 and 2, respectively, indicate that the aggregate meets the specification consistent with the test methods.

Table 1: Coarse aggregate properties

Test	Standard	Aggregate	Test results
Particle shape (flat)	BS 812	6/12 mm	23%
Particle shape (elongated)	BS 812	6/12 mm	17%
Particle shape (flat)	BS 812	4/10 mm	21%
Particle shape (elongated)	BS 812	4/10 mm	19%
Los Angeles	ASTM C 131	6/12 mm	24%
Water absorption	NP 581	6/12 mm	0.88%
Water absorption	NP 581	4/10 mm	1.24%
Specific gravity	NP 581	6/12 mm	2.66%
Specific gravity	NP 581	4/10 mm	2.65%

Table 2: Fine aggregate properties

Test	Standard	Test results
Methylene Blue Test	EN 933-9	0.02%
Sand Equivalent Test	EN 933-8	60%
Water absorption	NP 954	0.41%
Specific gravity	NP 954	2.61%

5.2. Properties of the asphalts

A Brazilian graded asphalt cement 50/70 pen asphalt was used in this study. This asphalt was used as a base to produce the asphalt rubber through the two systems: terminal and continuous blend. The crumb rubber from waste tires used to produce both asphalts rubber in this study was obtained from ambient grinding. The rubber gradation was tested in accordance with the requirements of ASTM C136, amended by the Greenbook recommendations (Greenbook, 2000). The rubber used followed the ADOT requirements type B (ADOT, 2005). Figure 2 shows the gradation of the ambient crumb rubber.

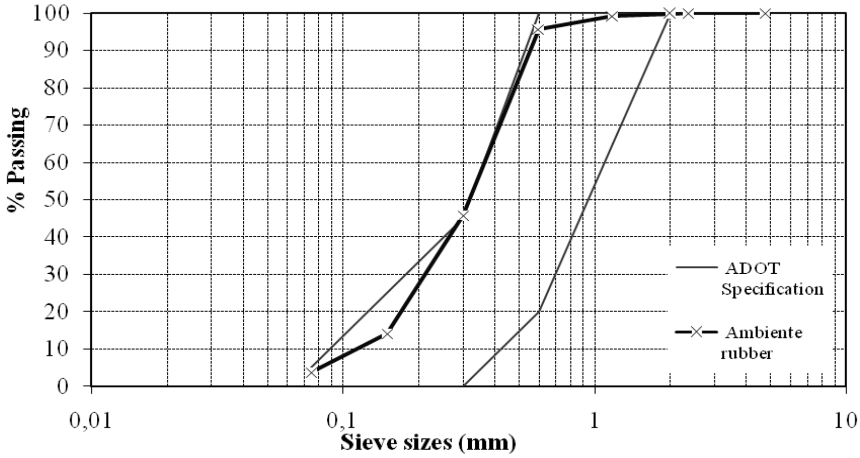

Figure 2: Gradation of ambient rubber

The terminal blend asphalt rubbers (TB) were used in two rubber concentrations, 15% and 20%, and were supplied by a Brazilian provider. The continuous blend asphalt rubber (CB), which was produced in laboratory, was optimized in terms of: % of crumb rubber; digestion time; digestion temperature. The results of the enhanced blend were: 17% rubber content by weight; 90 minutes of digestion time; 180 ºC digestion temperature. The laboratory characterization of the asphalt materials was carried out based on conventional tests, such as penetration, softening point, viscosity and aging (RTFOT – Rolling Thin Film Oven Test). The resilience test, usually related to modified asphalts, was also undertaken. The test results, which represent mean values of at least three asphalt rubber samples, are shown in Table 3.

Table 3: Properties of asphalts rubber

Test	Standard	Specification	TB (20%)	TB (15%)	CB (17%)
Penetration 25ºC, 100g, 5s (0,1 mm)	ASTM D 5	25 to 75	40	42	26
Softening Point – ring and ball (ºC)	ASTM D 36	54.4 min	68.0	67.7	65.0
Apparent viscosity (cP) at 175ºC	ASTM D 2196	1500 min	2178	1644	2829
Resilience (%)	ASTM D 5329	20	28	33	49
RTFOT 163ºC, 85 minutes	ASTM D 2872				
Change in mass (% de mass) max		0.6	0.3	0.3	0.3
Change in softening point (ºC)		-	1.0	2.9	8.5
Penetration 25 ºC, 100g, 5s (0,1 mm)		-	28.8	25.3	18.5
Retained penetration (%)		-	72.0	60.2	71.1
Apparent viscosity (cp) a 175 ºC		-	5350	1962	4800
Resilience (%)		-	39	36	46

5.3. Mixture gradation and design

In order to compose the mixtures, graded and gap graded were used. The conventional mixture (CON) was designed following the Brazilian specification grade “C”, DNIT-ES 031/2006 (Brazilian Department of Transport Infrastructures), using conventional 50/70 asphalt. The aggregate grain distribution produces a dense graded asphalt mixture usually applied in Brazilian flexible pavements.

The asphalt rubber mixtures were produced using either dense or gap gradations. The gap graded mixture used was the Caltrans ARHM-GG mixture (Asphalt Rubber Hot Mixture Gap Graded), designed according to the Caltrans Standard Special Provisions, SSP 39 400. The dense graded mixture produced with asphalt rubber was specified in accordance with the Asphalt Institute (AI), mix type IV. Figure 3 shows the gradation curves of these mixtures.

The Caltrans (C) gap graded mixtures were produced with both asphalt rubbers as follows: continuous blend asphalt rubber (mixture CCB) and terminal blend asphalt rubber with 20% of crumb rubber (mixture CTB). The Asphalt Institute (A) dense graded mixtures were produced using continuous blend asphalt rubber (mixture ACB) and terminal blend asphalt rubber with 15% of crumb rubber (mixture ATB).

The Marshall design procedure was used to determine the optimum asphalt content of the asphalt mixtures. Table 4 presents the mix design properties for the mixtures. The production of the samples of asphalt mixtures involved the following steps: i) aggregate and asphalt heating; ii) asphalt-aggregate mixing, iii) compacting and sawing of the mixture. In this study, the mixtures were compacted in slabs through the repeated passage of a vibrating cylinder over the asphalt mixture to obtain/reach the apparent density of the asphalt hot mixes defined in the design. Then, the slabs were sawed to produce prismatic specimens (50 mm x 63 mm x 380 mm) for stiffness and fatigue tests.

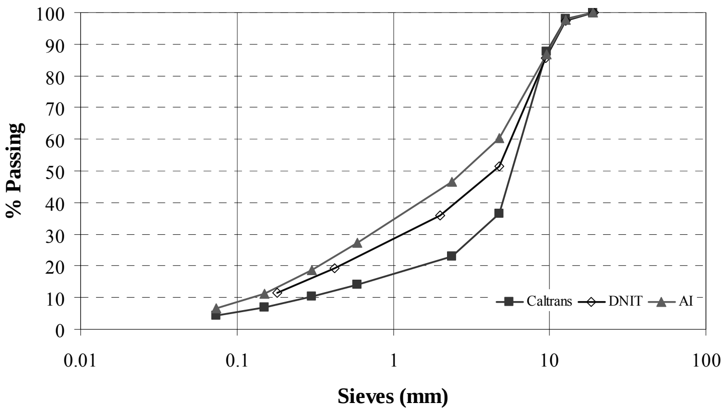

Figure 3: Gradation curves of the mixtures

Table 4: Marshall mixture design

Mixture	CON	CCB	CTB	ACB	ATB
Air voids (%)	5.0	6.0	6.0	5.0	6.0
Optimum binder content (%)	5.5	9.0	8.5	8.0	7.0

5.4. Dynamic modulus and fatigue

The test procedure for all mixtures included two types of test, frequency sweep and fatigue, which were conducted in accordance with the AASHTO TP 8-94 (Standard Test Method for Determining the Fatigue Life of Compacted HMA Subjected to Repeated Flexural Bending), through a four-point bending test in controlled strain (the strain was kept constant and the stress decreases during the test). Prior to the tests, the specimens were placed in an environmental chamber for 2 hours to reach the test temperature.

In the frequency sweep test, used to obtain the dynamic modulus and phase angle, seven frequencies were tested (10; 5; 2; 1; 0.5; 0.2; 0.1 Hz) in 100 cycles (for the first four ones) and 10 cycles (for the last three ones), at 20 ºC. The results of the tests are shown in Figures 4 and 5. The dynamic modulus of the conventional mixtures presents the highest modulus, because the addition of crumb rubber reduces the modulus of the asphalt rubber mixtures and enhances their flexibility. The results of the phase angle show that asphalt rubber mixtures have more elastic properties than the conventional ones.

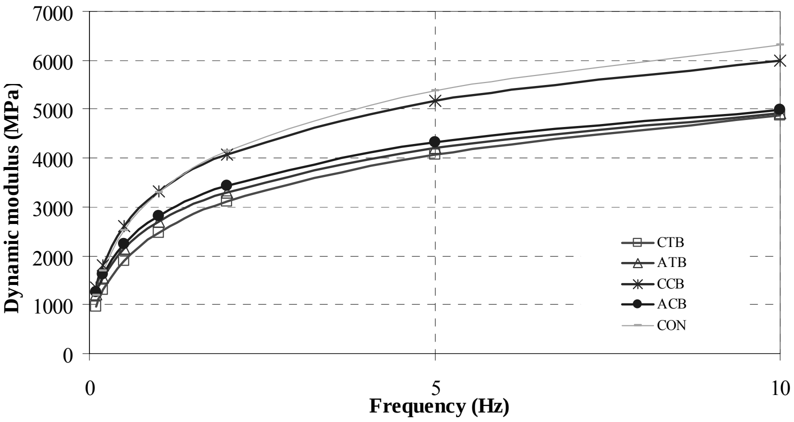

Figure 4: Dynamic modulus as function of load frequency

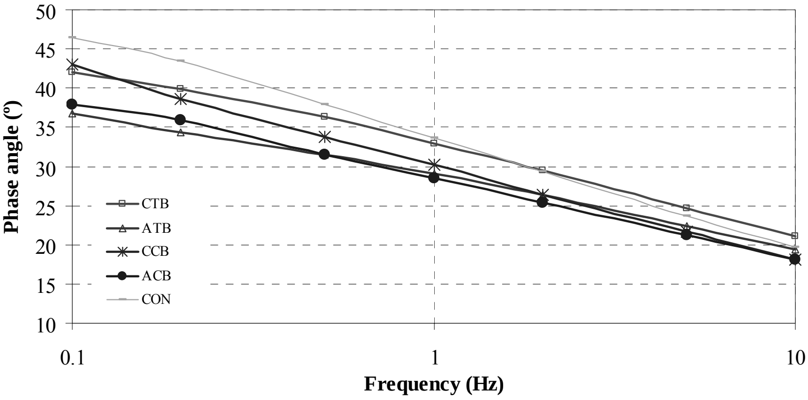

Figure 5: Phase angle as function of load frequency

The flexural fatigue tests were conducted in accordance with the AASHTO TP 8-94 and carried out at 20 ºC and at 10 Hz. Fatigue failure was assumed to occur when the flexure stiffness is reduced to 50 percent of the initial value (100th cycle). For every mixture, nine beam specimens were tested at three strain levels, 200, 400 and 800 (10^{-6} micro strains). The resulting fatigue curves are depicted in Figure 6. Figure 7 represents the fatigue life for a strain level of $100\text{x}10^{-6}$ (N_{100}), which is the strain level usually applied in empirical mechanistic pavement design.

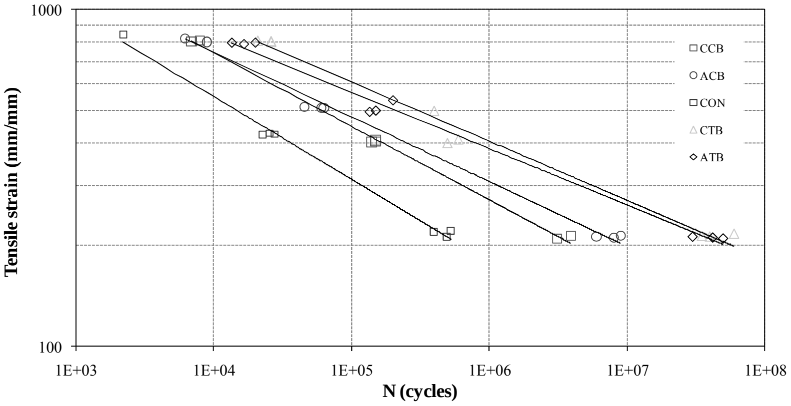

Figure 6: Fatigue curves of the mixtures

It was found out that the fatigue life was higher for asphalt rubber mixtures in comparison to conventional mixtures (CON). The order of magnitude of fatigue life for the asphalt rubber mixtures was remarkable considering that the CON mixture has 5.5% binder content, whereas the asphalt rubber mixtures have 7.0 % to 9.0%. Terminal blend mixtures exhibit better fatigue life than the continuous blend mixtures in comparison to asphalt rubber mixtures.

To evaluate the influence of the binder properties in the fatigue resistance, a series of graphics is presented, in which the fatigue life, expressed in terms of N_{100}, is presented as function of the asphalt penetration (Figure 8), softening point (Figure 9), resilience (Figure 10) and apparent viscosity (Figure 11). Only the softening point seems to be a potential indicator of the fatigue performance of asphalt rubber mixtures.

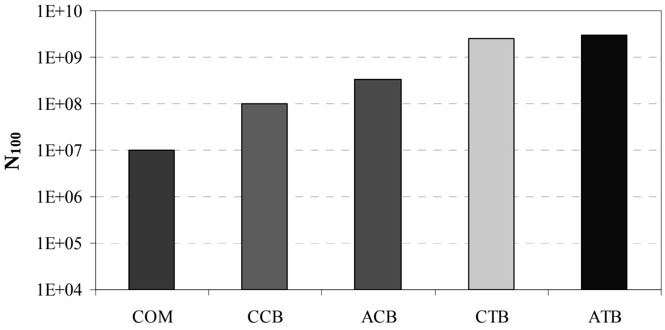

Figure 7: Fatigue life (N_{100})

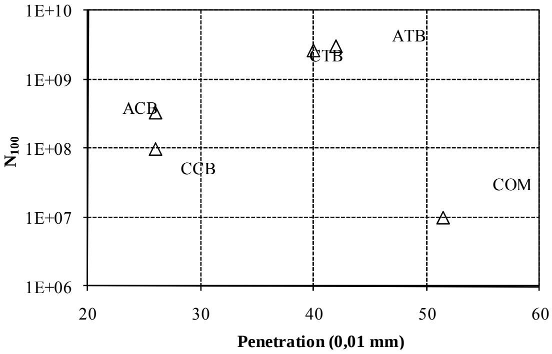

Figure 8: Comparison between fatigue life (N_{100}) and penetration

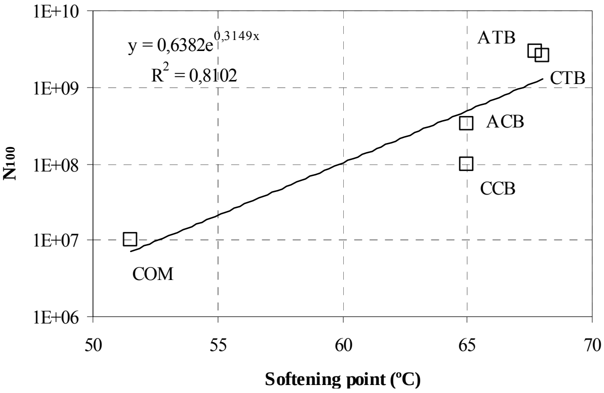

Figure 9: Comparison between fatigue life (N_{100}) and softening point

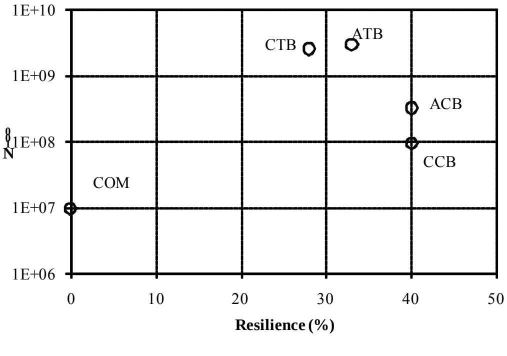

Figure 10: Comparison between fatigue life (N_{100}) and resilience

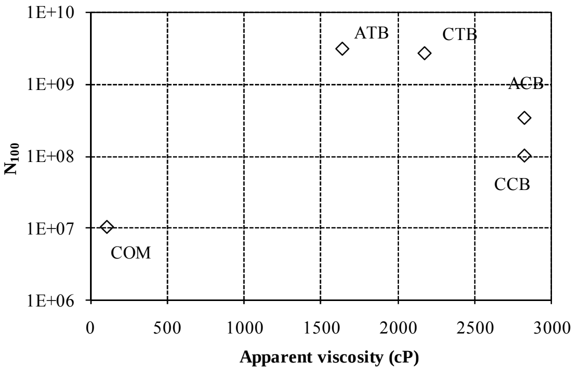

Figure 11: Comparison between fatigue life (N100) and apparent viscosity

6. CONCLUSIONS

In this study the effects of fatigue behavior in four asphalt rubber mixtures produced through the wet process were analyzed. Two mixtures were gap graded (Caltrans ARHM-GG) and the other two were dense graded AI type IV. Terminal blend and continuous blend asphalt rubber were obtained. The fatigue performance of these mixtures was compared to a conventional asphalt concrete dense-graded mixture (grade "C", DNIT-ES 031/2006), a typical mixture used in pavements in the South of Brazil. The crumb rubber and the asphalts were previously tested in laboratory. Fatigue tests were conducted on beam specimens obtained in laboratory. Both stiffness and fatigue were determined by using controlled strain fatigue beam tests performed at 20 ºC and 10 Hz. Based on the test results obtained in this study, the following conclusions can be drawn:

- crumb rubber can be a proper means to improve conventional asphalt properties;
- the use of asphalt rubber in asphalt mixtures results in asphalt mixtures with a higher optimum binder content than that shown by conventional mixtures;
- in general, the stiffness of the asphalt rubber mixtures are lower than that of the conventional ones, used as reference;
- the lower phase angle of the asphalt rubber mixtures obtained in this study indicates that these mixtures have better elastic properties in comparison to the conventional ones;
- fatigue tests indicate that the conventional asphalt mixtures showed poor performance if compared to the typical asphalt mixtures;
- the asphalt rubber mixtures obtained through the terminal blend system require a lower binder content than the mixtures produced with continuous blend mixtures;
- the terminal blend mixtures presented a higher fatigue life than the continuous blend mixtures;
- the dense graded terminal blend asphalt rubber AI mix type IV showed the best performance in terms of fatigue life.

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