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The Improvement of Pavement Performance Using Asphalt Rubber Hot Mixes

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Abstract

The need of a better pavement performance has led researchers to develop new road materials, mainly for the asphalt layers, where the modification of the asphalt is the main example. This modification usually forces the use of polymers and fibers and, more recently, the use of crumb rubber from ground tires, where the modified asphalt is known as asphalt rubber. This asphalt rubber used in asphalt mixtures produces a superior performance if compared to the asphalt mixtures with conventional asphalt. The crumb rubber modification of the asphalts also presents a higher resistance to climatic effects, compared to the other binders. Based on these assumptions, this paper presents the results of the evaluation of mechanical properties, related to the pavement performance, of asphalt rubber mixtures when compared to conventional mixtures. Two types of aggregate were used (pebble and diorites) and two binders utilized (asphalt rubber and conventional asphalt). The aging effect due to the asphalt mixture production and compaction was taken into account. The materials performance was evaluated through stiffness, fatigue and permanent deformation tests. Reflective cracking performance was also predicted using a mechanistic-empirical method.

KEYWORDS: pavement performance; asphalt; rubber hot mix.

1. INTRODUCTION

1.1. Aggregate gradation

The aggregate gradation of a conventional mixture is defined according to the maximum aggregate size and the main applications for the material. The typical thickness of the layer where the mixture will be applied on is considered in the selection of the aggregate gradation. Some recommendations for the aggregate gradation, mainly due the permanent deformation, were drawn during the SHRP program, which led to the definition of the restricted zone. The restricted zone, around the maximum density line, is defined by some control points to avoid the lack of stability of the asphalt mixture.

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For asphalt rubber mixtures, some recommendations should be defined once the binder used in these mixtures presents more viscosity and the content normally doubles that of traditional mixtures. Asphalt rubber mixtures have more than 7.5% of binder content, but this value can reach 9.5% for certain applications. The inclusion of such amount of binder in asphalt mixtures is obtained by acting in the aggregate gradation. In this case two types of aggregate gradations were used for asphalt rubber mixtures: the gap-graded and the open-graded gradation. The gap-graded gradation produces a rough asphalt rubber mixture and the open-graded gradation produces a draining mixture. These two aggregate gradations allow using a high content of binder in the mixtures and a highly viscous binder.

The typical aggregate gradations (gap-graded and open-graded) used in asphalt rubber mixtures are presented in Table 1 and represented in Figure 1.

Table 1 – Aggregate gradations (% passing) used for asphalt rubber mixtures

Sieve Size	Gap-graded		Open-graded	
19.0 mm (3/4 in.)	100	100	100	100
12.5 mm (1/2 in.)	85	100	100	100
9.5 mm (3/8 in.)	70	85	90	100
4.75 mm (No. 4)	28	40	35	50
2.00 mm (No. 10)	12	20	6	10
0.425 mm (No. 40)	6	12	3	7
0.075 mm (No. 200)	2	5	2	3

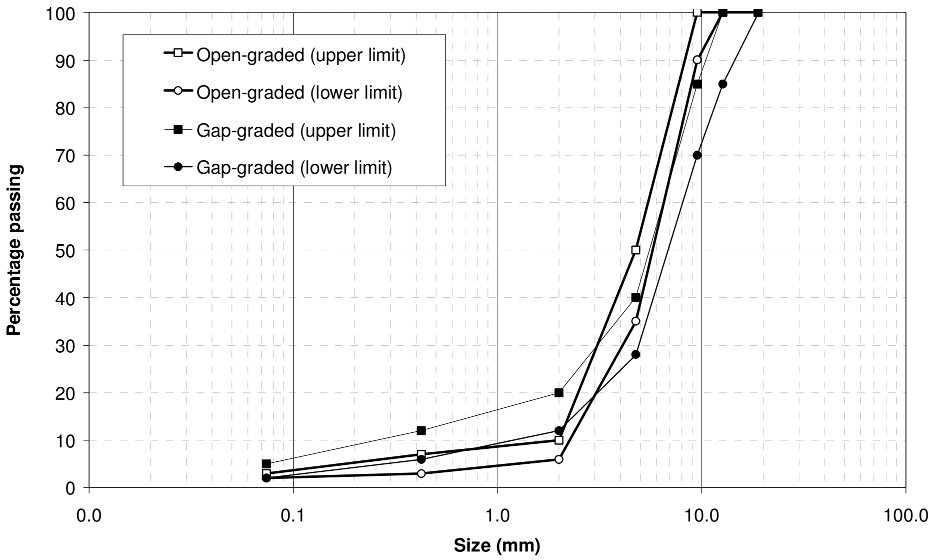

Figure 1 – Aggregate gradation curves used for asphalt rubber mixtures

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The analysis of Figure 1 allows concluding that both aggregate gradation curves are very similar. In the fine part of the aggregate gradation (up to 2 mm), open-graded mixtures present less fine particles than gap-graded mixtures. In the coarse part of the aggregate gradation the gap-graded has also fewer particles than the gap-graded mixture.

Despite these differences, the most important aspect of these aggregate gradation curves is the fact that, for open-graded mixtures, the upper and lower limits are very closed thus requiring a suitable quality control to ensure the quality of the material.

1.2. Crumb rubber

The modification of asphalt to obtain asphalt rubber is made by the digestion of crumb rubber into asphalt. The crumb rubber is obtained through grinding of the tires using two different techniques: ambient grinding and cryogenic process.

Ambient grinding can be accomplished in two ways: granulation and crackermills. Ambient describes the temperature of the rubber or tire as it is being size reduced. Typically, the material enters in the crackermill or granulator at ambient or room temperature. The temperature of the rubber will rise significantly during the process due to the friction generated, as the material is being torn apart. Through granulation the rubber size is reduced by means of cutting and shearing actions. The rubber particles produced in the granulation process generally have angular surface shape, rough in texture, with similar dimensions on the cut edges.

Cryogenic processing uses liquid nitrogen or other materials/methods to freeze (-87 °C to -162 °C) tire chips or rubber particles prior to size reduction. The surface is glasslike, and thus has a much lower surface area than ambient ground crumb rubber of similar gradation. Cryogenic grinding is a cleaner, slightly faster operation resulting in the production of fine mesh sizes. The main disadvantage is the slightly higher production cost due to the added cost of liquid nitrogen (Baker et al., 2003).

These two types of crumb rubber produce rubber with different particle shapes. Crumb rubber particles produced through the ambient process generally have a porous or fluffy appearance (Amirkhanian and Shen, 2005). On the other hand, in the cryogenic process, the surface of the crumb rubber is glasslike, and thus has a rather lower surface area than ambient ground crumb rubber with similar gradation (Baker et al., 2003). These conclusions can be observed in Figure 2 obtained from Scanning Electron Microscopy.

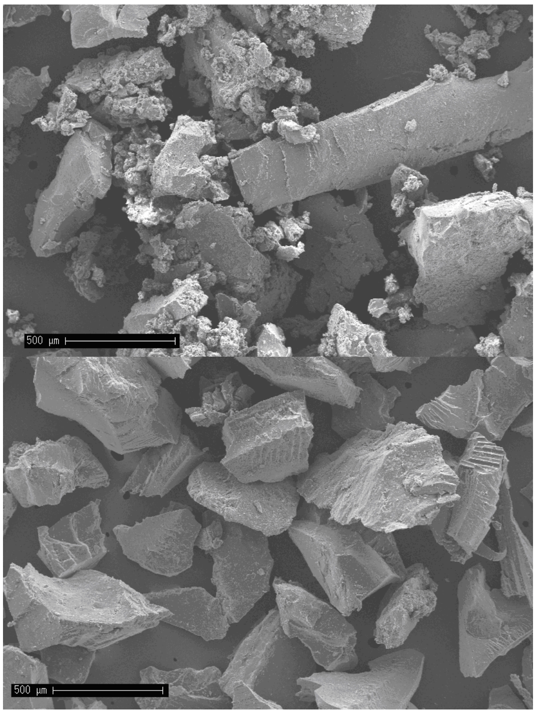

Figure 2 – Ambient crumb rubber (left) cryogenic crumb rubber (right)

Typically, the crumb rubber gradation, resulting from ambient grinding and from cryogenic process, to be used in the production of the asphalt rubber, is presented in Figure 3, where the main differences appears in the fine part of the gradation.

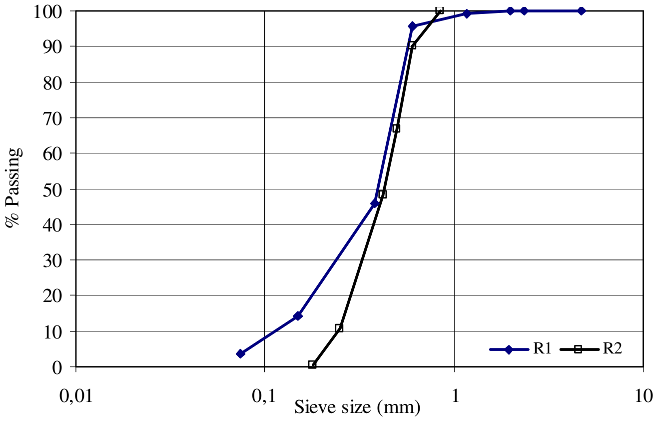

Figure 3 – Grain size distributions for rubber types (R1 – ambient grinding; R2 – cryogenic process)

1.3. Asphalt rubber

The production of the asphalt rubber is a process characterized by the incorporation of crumb rubber into asphalt. It is not a simple addition of crumb rubber into asphalt. The modification of the asphalt is obtained through the digestion of the crumb rubber by the asphalt during a certain period of time.

The compatibility of the asphalt/rubber system guarantees the achievement of asphalt rubber with its common properties. Compatibility can be characterized not only in terms of the achievement of a particular morphology, i.e. the structural arrangement of the polymer particles, chains or groups within the asphalt matrix, but also in terms of thermodynamic stability, i.e. if the conformation of the polymer particles or chains that may be in a low energy state. It may also be characterized in terms of practical storage stability. Finally, it may be based on the fact that a given property or set of properties are achieved and can be maintained for a suitable period of time (Holleran and Reed, 2000).

The interaction between rubber particles and asphalt is characterized by the fact that the asphaltenes and light fractions of the conventional asphalt binder and the rubber particles interact to form a gel coated particle (Figure 4). Rubber particles swell in a process similar to what occurs in polymer asphalt systems. The large increase in viscosity along the early times of digestion is due to the continuation of this solvation process. However, this system is not thermodynamically stable and leads to significant change of properties throughout time (Neto et al., 2006).

The design of asphalt rubber requires the definition of some variables which include the amount of crumb rubber, digestion time and temperature, based on the base asphalt properties. Hard asphalts can only interact with low crumb rubber content while soft asphalts interact with high crumb rubber content.

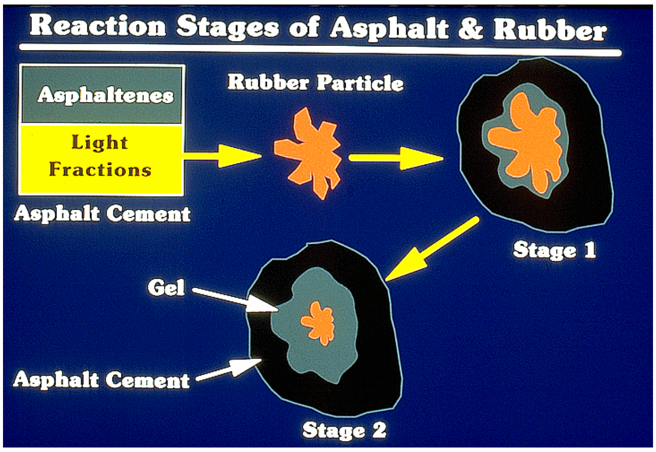

Figure 4 – Interaction between asphalt rubber and asphalt (Holleran and Reed, 2000)

The criteria to establish the proper rubber content and the digestion time and temperature are usually based on physical tests carried out in the asphalt rubber, i.e. penetration, softening point, resilience and, most important, viscosity. The addition of crumb rubber to the base asphalt increases viscosity significantly due to the gel and swelling.

In Figure 5 the influence of crumb rubber content on the asphalt rubber characteristics for two base asphalts (35/50 pen and 50/70 pen asphalt) is illustrated. These results were obtained for a digestion time of 45 minutes and a temperature of 175 ºC.

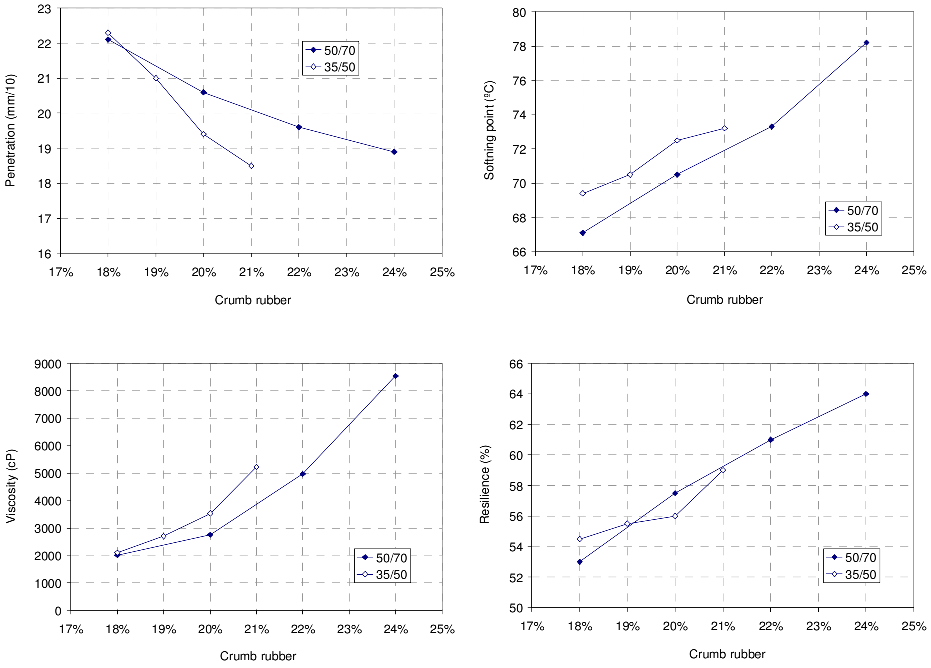

Figure 5 – Influence of crumb rubber content on the asphalt rubber characteristics

The results of the design of the asphalt rubber allow observing that the increase of crumb rubber reduces penetration: the more content of crumb rubber, the harder asphalt rubber becomes. The same conclusion may be drawn for viscosity and softening points. In terms of resilience, the increase in crumb rubber produces a more elastic asphalt rubber.

As expected, these two types of asphalts that are used to produce asphalt rubber produce different final products. The main difference is that the 50/70 pen asphalt allows adding about 1% more crumb rubber than the 35/50 pen asphalt.

The design of asphalt rubber is intended to define the crumb rubber content necessary to produce asphalt rubber. The main reason for choosing the crumb rubber content has to do with the asphalt rubber viscosity, as it is important in order to ensure a correct mixing of the binder with the aggregates and a correct compaction of the final mix.

The production of asphalt rubber mixes is mainly made by using the continuous blend process in which asphalt rubber is produced near the asphalt mix plant with the help of specific equipment, and supplied to the asphalt mix plant in accordance with needs. To reach the asphalt mix plant, asphalt rubber needs to have a specific viscosity to be pumped appropriately. Nowadays equipments can supply asphalt rubber with a viscosity inferior to 5000 cP.

Based on the presented results, a content of 22% crumb rubber may be used to produce asphalt rubber with the 50/70 pen asphalt. For the 35/50 pen asphalt, only 20% crumb rubber can be used.

1.4. Asphalt rubber hot mixture

There are two methods through which asphalt-rubber mixtures are produced: wet process and dry process. In the wet process, the conventional binder is heated up at temperatures around 180ºC in a super-heating tank in hermetic conditions and immediately transported to an adapted mixture tank. In the mixture tank, crumb rubber is added to the preheated conventional binder.

In the dry process, dry particles of crumb rubber are added to the preheated aggregate before adding a conventional binder (Visser and Verhaeghe, 2000).

The aggregate is heated at temperatures of approximately 200ºC. Then the crumb rubber is added and the mixing continues for approximately 15 seconds or until the formation of a homogeneous composition of aggregate-crumb rubber. After that, a conventional binder is added to the mixture aggregate-crumb rubber following conventional methods in a mixing plant.

The structural performance of the asphalt rubber hot mixtures is directly related to the mechanical properties of the asphalt rubber binder used. In this type of mixtures, the binder content is around 7.5% to 9.5%, what has an important effect on the material performance mainly in terms of fatigue response where it is expected to have at least 10 times more fatigue life than a conventional asphalt mixture where the binder content is about 5% (Minhoto et al., 2005). This behavior is attributed to the larger flexibility of the mixtures provided by the incorporation of crumb rubber into the conventional binder.

In terms of permanent deformation, several studies indicate a satisfactory performance of asphalt rubber hot mixes in relation to those produced with conventional binders, mainly due to the aggregate gradation used to produce the mixture and due the thickness of the layers where the mixture is placed (Antunes et al., 2000).

Asphalt rubber mixtures have their principal application in the field of pavement rehabilitation, where reflective cracking resistance is the main property required from mixtures. An experience of more than 30 years of application of these mixtures in very cracked pavements shows their capacity for retarding crack propagation from the old pavement to the surface (Way, 2006).

2. OBJECTIVE

The research presented in this paper reports some of the results of a project undertaken by the University of Minho in the study of the modification of the asphalt using crumb rubber and the evaluation of the performance of asphalt rubber mixtures used in pavement rehabilitation.

For this work some asphalt mixtures with different compositions were studied aiming at pavement rehabilitation. Two types of aggregate, pebbles and diorites, mixed with two binders, namely 35/50 pen asphalt and 35/50 pen asphalt modified by crumb rubber were used.

The material performance was evaluated through stiffness and fatigue tests carried out in a four point bending device and the permanent deformation tests were carried out in the wheel tracking device. The aging effect due the production and compaction of the mixture was also regarded. The reflective cracking was assessed through the application of an empirical-mechanistic approach which uses fatigue test results to evaluate the cracking reflection resistance.

3. MATERIAL USED IN THIS WORK

The asphalt mixtures studied present a composition defined in Table 2, where it can be observed the existence of two mixtures with diorite aggregate and three mixtures with pebble aggregate. The binder was asphalt rubber produced with conventional 35/50 pen asphalt modified by 19% of crumb rubber and conventional 35/50 pen asphalt without any modification. The aging effect was applied to both mixtures to simulate the production and compaction of the asphalt mixtures. This aging was induced by placing the asphalt mixture in an oven at 85ºC during 5 days as proposed by the SHRP program.

Table 2 also presents the physical characterization of the materials tested in this project expressed in terms of air void and binder content. The asphalt rubber mixtures with a gap-graded aggregate gradation had, on average, 8.3% binder content. For the conventional mixtures the binder content was about 5.3%, which represents a typical value for wearing course mixtures. In terms of air void content, the asphalt mixtures presented values of about 5%, whereas for the conventional mixtures the air void content was about 3.5%.

Table 2 – Asphalt mixtures description

Asphalt mixture	**Aggregate**	**Binder**	**Aging effect**	**Air void content (%)**	**Binder content (%)**
D-AR-N	Diorite	Asphalt rubber	No	4.7	8.0
P-C-N	Pebble	Conventional 35/50 pen asphalt	No	3.3	5.6
P-AR-N	Pebble	Asphalt rubber	No	2.6	8.5
P-C-Y	Pebble	Conventional 35/50 pen asphalt	Yes	3.8	5.1
D-AR-Y	Diorite	Asphalt rubber	Yes	5.7	8.4

4. STIFFNESS AND FATIGUE RESISTANCE

The test procedures to characterize the stiffness and fatigue resistance of all the studied mixtures included two tests: (i) frequency sweep tests; (ii) fatigue tests. Prior to the tests, the specimens were placed in an environmental chamber for nearly 2 hours in order to reach the test temperature.

The configuration used in this study was based on the four-point bending test in controlled strain, what means that the strain is kept constant and that the stress decreases during the test. In general, controlled strain testing has been associated with thin pavements. The test configuration is represented in Figure 6. The bending device and the servo-hydraulic testing machine are shown in Figure 7.

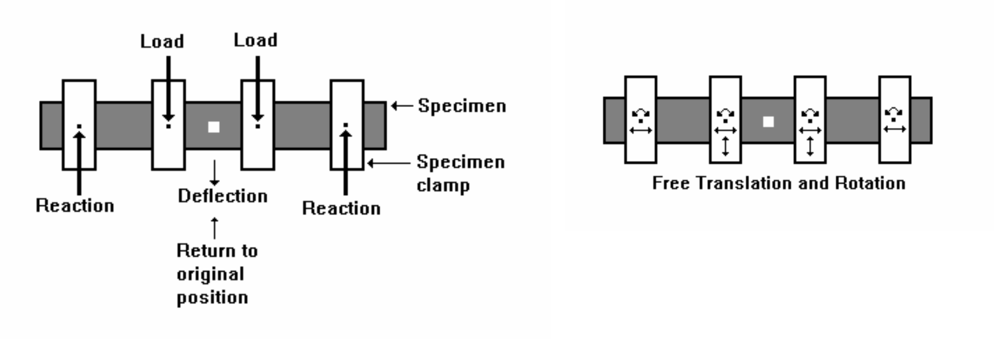

Figure 6 – Schematic representation of the four point test setup

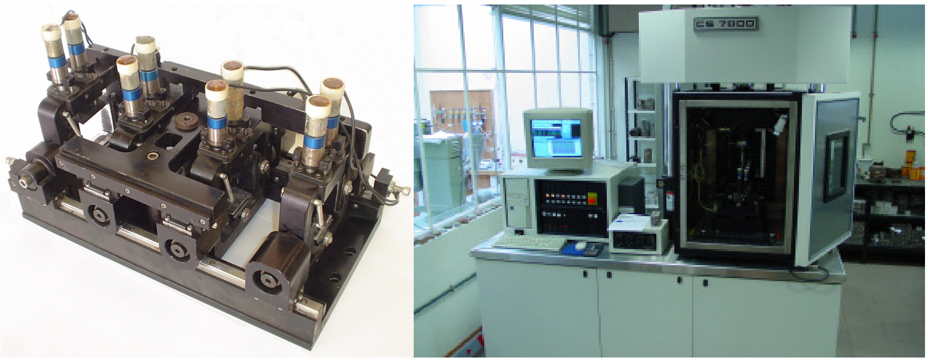

Figure 7 – Four point bending device and servo-hydraulic testing machine

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). All tests were carried out at 20 ºC and at 10 Hz. The flexural beam device allows testing beam specimens up to 50 mm x 63 mm x 380 mm. Fatigue failure was assumed to occur when the flexure stiffness is reduced to 50 percent of the initial value, as shown in Figure 8. Before the fatigue test, the frequency sweep test was conducted in the same testing equipment, using the same specimen.

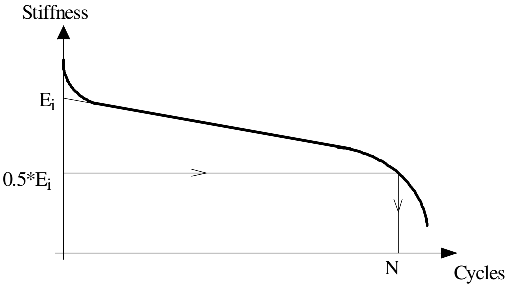

Figure 8 – Stiffness evolution during fatigue tests and definition of test failure

The frequency sweep test measures the stiffness and the phase angle of mixtures when subjected to different loading frequencies. In this study, seven frequencies were tested (10; 5; 2; 1; 0,5; 0,2; 0,1 Hz) in 100 cycles to avoid damage in the specimen. The stiffness and phase angle of the studied mixtures, conducted at 20 ºC, are shown in Figures 9 and 10, respectively.

The analysis of the obtained results allows concluding that the asphalt rubber mixtures exhibit lower stiffness than the conventional mixtures. At 10 Hz, the asphalt rubber mixtures present stiffness moduli that range between 1900 MPa up to 3200 MPa, depending on the aggregate type, gradation and air void content. On the other hand, conventional mixtures present stiffness values higher than 6000 MPa.

In terms of phase angle, asphalt rubber mixtures present values that are in the same range as conventional mixtures. This allows concluding that the expected permanent deformation resistance is probably in the same range of conventional mixtures.

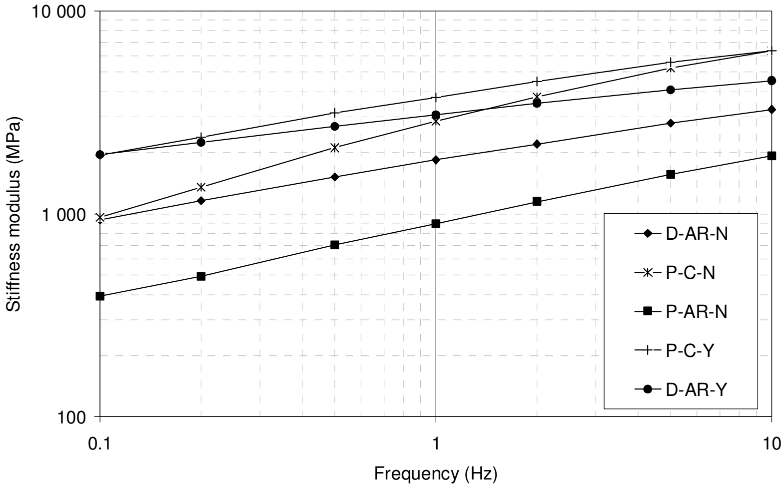

Figure 9 – Stiffness modulus of the studied mixtures

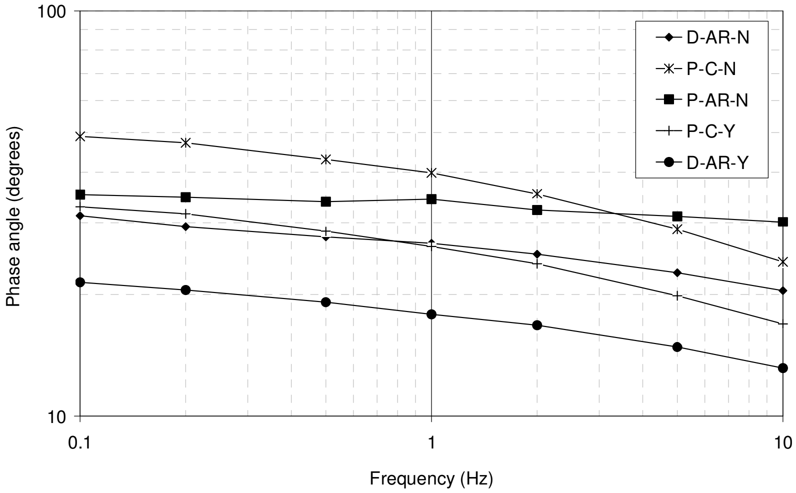

Figure 10 – Phase angle of the studied mixtures

The aging applied to the specimen prior the test had a reduced influence in both mixtures. In conventional mixtures the aging effect was only visible at low test frequencies. In asphalt rubber mixtures the aging effect increased the stiffness modulus of 1000 MPa.

The stiffness modulus and phase angle at 10 Hz for all mixtures can be observed in Table 3.

Table 3 – Stiffness and phase angle at 10 Hz

Asphalt mixture	**Stiffness modulus (MPa)**	**Phase angle (degree)**
D-AR-N	3266	20.4
P-C-N	6350	24.0
P-AR-N	1929	30.1
P-C-Y	6378	16.9
D-AR-Y	4529	13.1

The fatigue tests carried out on the studied mixtures were performed according to the AASHTO TP 8-94 at 20 ºC and 10 Hz. For each mixture, six specimens were tested at two different strain levels and the results were fitted in fatigue laws represented in Figure 11.

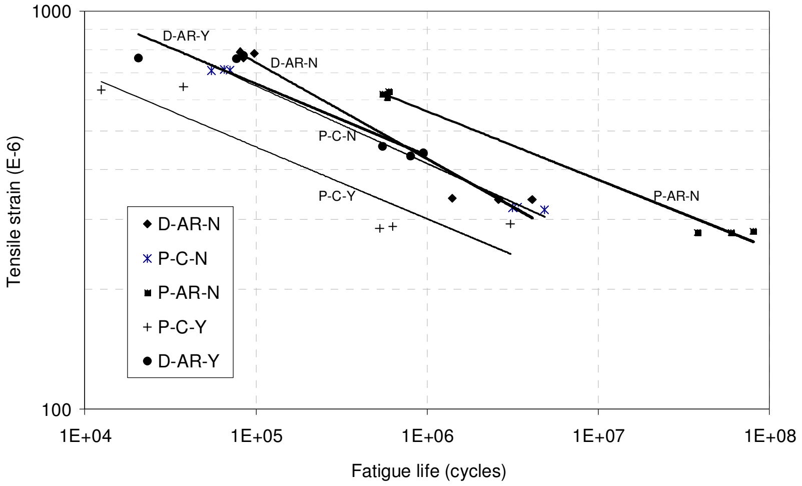

Figure 11 – Fatigue curves of the studied mixtures

The analysis of these results allows concluding that mixtures with asphalt rubber have an important increase in terms of fatigue life if compared to the mixtures with conventional binder. This difference is about 10 times superior as it can be observed from the comparison between mixture P-AR-N and mixture P-C-N. The aging in asphalt rubber mixtures is not significant, as it was observed in mixtures (D-AR-N and D-AR-Y) unlike to what happens in mixtures with conventional binder (P-C-N and P-C-Y). The use of different aggregate types can also lead to different fatigue responses, as observed in mixtures P-AR-N and D-AR-N, where the difference in terms of fatigue life is about 5 times superior.

5. PERMANENT DEFORMATION RESISTANCE

Rutting in asphalt concrete layers develops gradually from the number of load applications, and it usually appears as longitudinal depressions on the wheel paths accompanied by small upheavals on the sides. It is caused by a combination of densification (a decrease of volume and hence, an increase of density) and shear deformation (Sousa et al., 1994).

To complement the comparison study between mixtures with and without asphalt rubber, and once the mixtures with pebble aggregate showed excellent fatigue behaviour, permanent deformation tests on this mixture were carried out to verify the resistance of these mixtures.

The permanent deformation resistance tests were performed on P-C-N and D-AR-N mixtures, following the NLT 173-94 standard and using a wheel tracking testing device. The tests were carried out at 60 ºC test temperature. A contact tension of 700 KPa was applied, as recommended in the BS 598-110:1998 standard.

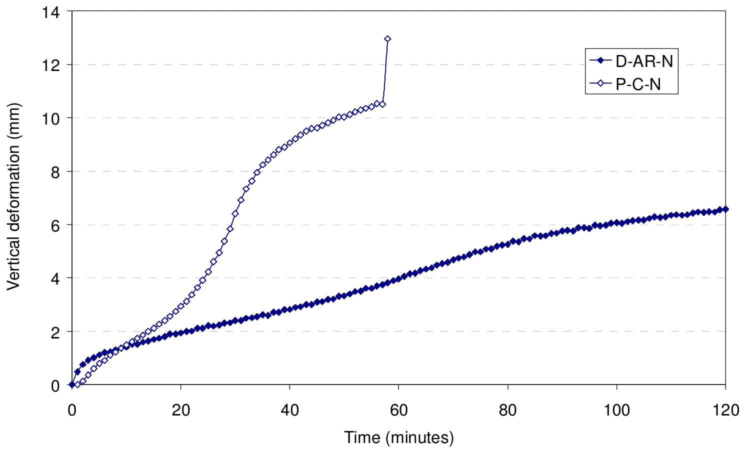

Figure 12 – Permanent deformation resistance

The results expressed in terms of vertical deformation throughout time are presented in Figure 12, where it can be observed that the asphalt rubber mixture (D-AR-N) presents the highest permanent deformation resistance if compared to the conventional mixture (P-C-N).

6. REFLECTIVE CRACKING RESISTANCE

When a mixture is applied on a pavement overlay it is subjected to cracking propagation, directly above the cracks of the existing pavement due to static and repetitive loading during the first few years of service. This type of distress is traditionally known as "reflective cracking" and it is a major problem for highway agencies throughout the world. Thus, road administrations are concerned about the prevention of cracking occurrence, in order to provide a good functional and structural performance for their pavements.

The temperature variations, daily and seasonal, and associated thermal stresses could be some of the causes for premature overlay cracking, affecting the overlay life of asphalt pavements. In regions that experience large daily temperature variations or extremely low temperatures, thermal conditions play a major role in the reflective cracking response of a pavement. On the one hand, binder properties, such as stiffness, ageing or penetration among others, are sensitive to temperature variations. On the other hand, the combination of two of the most important effects - wheel loads passing on or near the cracks and the increasing tension in the material above the crack (i.e. in the overlay) due to a rapid decrease of temperature - have been identified as the most probable causes of high states of stress and strain above the crack and responsible by the reflective cracking phenomena.

The evaluation of the reflective cracking resistance for the studied mixtures was carried out through the mechanistic-empirical method developed by Sousa et al. (2002), which uses fatigue resistance and stiffness to predict the overlay life.

The mechanistic-empirical methodology is capable of assembling simultaneously Modes I and II crack opening. The influence of pavement characteristics on the state of stress and strain was considered by defining a deviator strain such as the Von Mises stress. This mechanistic-empirical methodology is based on the results of flexural fatigue tests, in controlled strain, based on the Von Mises deviator strain as the “controller” parameter of the phenomenon. For beam fatigue test conditions subjected to four-point bending the tensile strain can be correlated to the Von mises strain.

The application of this method required a pavement to be rehabilitated. The one considered had a subgrade of 110 MPa, a granular layer of 25 cm with 250 MPa and 17 cm of existing asphalt layer with 2250 MPa. The results of the method application led to the overlay thickness defined in Figure 13.

As it can be observed in that figure, for the same overlay life, the asphalt rubber mixture requires half of the overlay thickness of the conventional mixture.

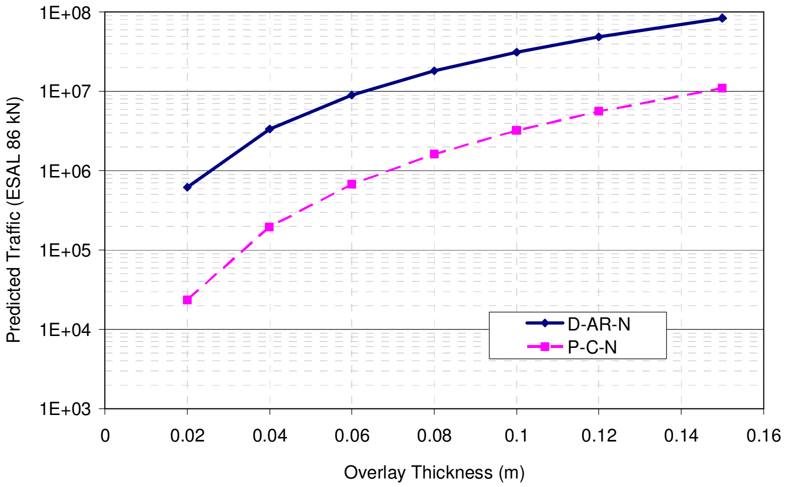

Figure 13 – Estimation of overlay life

7. CONCLUSIONS

The study undergone in this project and presented in this paper reports the evaluation of pavement performance based on the asphalt material properties herewith studied and the contribution of asphalt rubber mixtures to the improvement of pavement performance.

The study was carried out by considering mixtures with two different type of aggregates (pebble and diorite), and two types of asphalt binder (asphalt rubber and conventional asphalt). The aging induced by the asphalt mix production and compaction was also considered.

The asphalt mixture performance was assessed by stiffness, fatigue and permanent deformation tests and reflective cracking performance.

The results allowed to conclude that the stiffness of asphalt rubber mixtures is inferior to the one obtained from conventional mixtures. In terms of fatigue response, asphalt rubber mixtures exhibit about 10 times more fatigue resistance than conventional mixtures. The aggregate type has a significant influence on the fatigue response. Asphalt mixtures with pebble aggregate presented a longer fatigue life than those produced with diorite aggregate.

The permanent deformation study showed that the mixture with diorite aggregates and asphalt rubber had more permanent deformation resistance than the conventional mixture with diorite aggregates.

The application of the reflective cracking prediction model to the same mixtures here evaluated through the permanent deformation study confirmed the superior behaviour of asphalt rubber mixtures.

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