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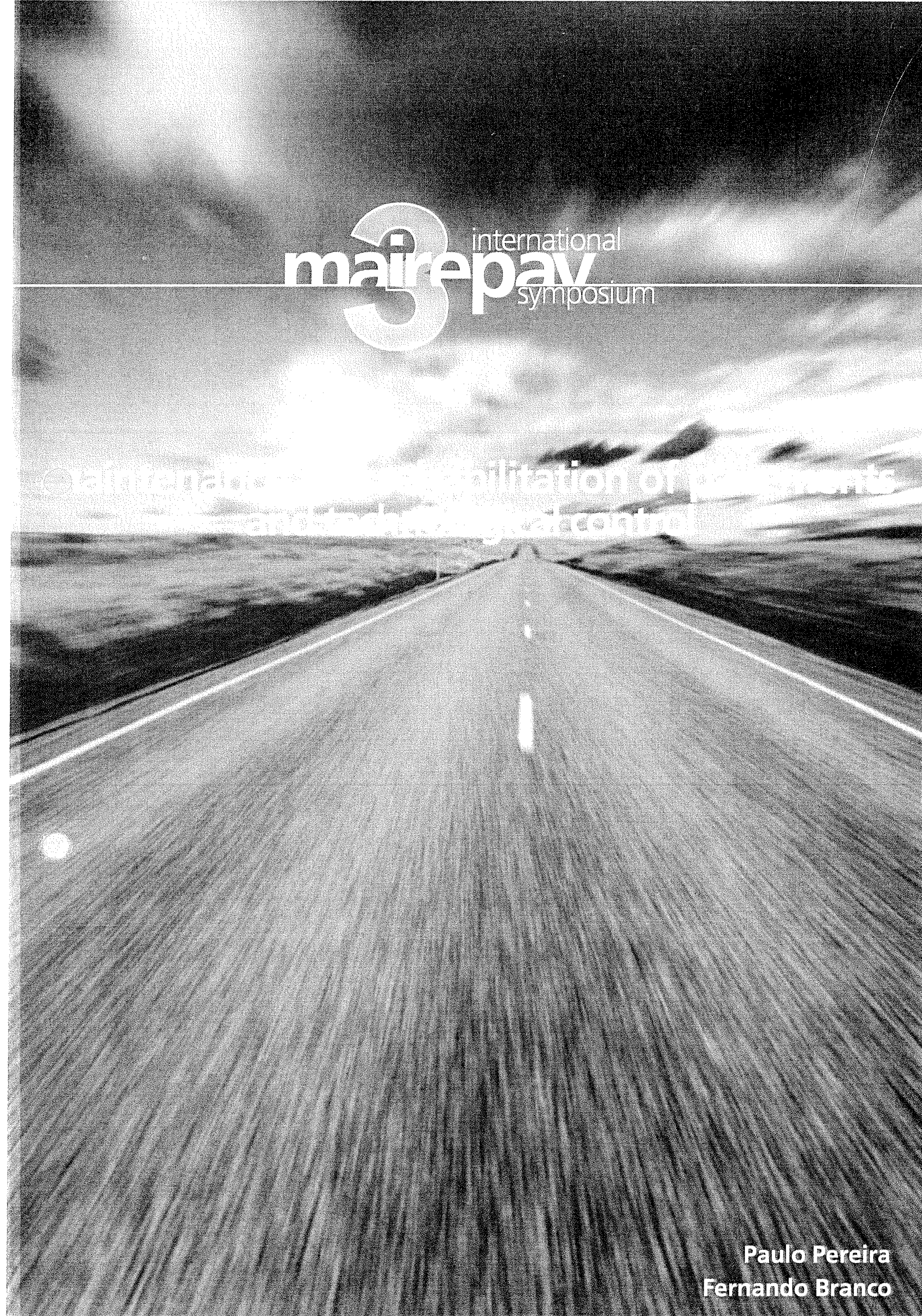

Maintenance and rehabilitation of pavements and technological control

Paulo Pereira
Fernando Branco

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Optimization of Asphalt Rubber Hot Mixes Based on Performance Laboratory Tests

S. Neto & M. Farias
Pos-graduate Program in Geotechnics, University of Brasilia, Brazil.

J. Pais & P. Pereira
Department of Civil Engineering, University of Minho, Portugal.

ABSTRACT: Asphalt binders modified with crumb rubber recycled from ground tires have been successfully used in asphalt mixtures improving the mechanical and functional behaviour of the pavements. This paper shows the influence of several factors that affect the behaviour of asphalt-rubber (AR) and of hot mixes made with this material. Modified binders were prepared using a straight binder with 35/50 penetration and rubber obtained by the environmental process. Samples of asphalt-rubber were collected at different digestion time and temperature and conventional characterization tests were performed. Gap-graded hot mixes were prepared using 8% of modified AR binder and resilient modulus and fatigue tests were carried out. Tests with the modified binder showed a great influence of the rubber content, digestion time and temperature in the asphalt-rubber behaviour. The results of mechanical tests revealed that an increase of rubber content enhances fatigue life and decreases the resilient modulus of the asphalt mixes studied.

KEYS WORDS: Pavements, Asphalt-rubber, Asphalt hot mixes.

1. INTRODUCTION

Most of Brazilian paved roads were constructed with flexible pavements and exhibit severe damages. According to the annual report of the National Confederation of Transport, more than 50% of the Brazilian pavements are in a state considered regular or poor (CNT, 2001). The most common damage is excessive cracking due to fatigue and rutting due to permanent deformations.

An alternative solution to reduce fatigue cracks is the use of asphalt binders modified crumb rubber recycled from ground tires, also known as asphalt-rubber. Countries like the United States, South Africa, Australia and some countries in Europe have accumulated a lot of experience with the use of this material. Laboratory and site tests in asphalt mixes using asphalt-rubber show and an excellent structural performance, besides functional benefits. There have been reports on increase of fatigue life of surface courses and reduction of reflective cracks, increase of skid resistance and reduction of noise level. All this features have a positive impact in reducing maintenance costs.

Besides structural and functional aspects, there is an important environmental factor related to the use of asphalt-rubber. According the National Association of Tire Industries (ANIP), the annual tire production in Brazil is of about 45 million units. About 100 million units of scrap tire are spread in dumping areas, rivers and lakes in Brazil. A recent resolution of Brazilian National Council for the Environment (CONAMA Resolution N° 258 of 26 of August 1999) requires all tire makers and dealers to recycle 25% of their production in the year 2002, 50% in 2003 and 100% in 2004. Since asphalt-rubber contains in average 20% in weight of crumb rubber, it provides an efficient means to get rid off this huge quantity of used tires produced daily.

The objective of this paper is to study the influence of the main factors that affect the mechanical behaviour of asphalt hot mixes produced with asphalt-rubber obtained by the wet process. These factors include the size and content of incorporated crumb rubber, and the temperature and time of digestion. The properties of the modified binder (AR) were investigated by means of conventional laboratory tests such as penetration, softening point, resilience and Brookfield viscosity. Resilient modulus and fatigue tests were used to investigate the mechanical behaviour of gap graded hot mixes.

2. BACKGROUND

The use of the modified binder with crumb rubber recycled from ground tires in asphalt hot mixes was initiated in 1940's. The incorporation of the crumb rubber recycled from ground tires to asphalt binders had as objective, to improve the mechanical behavior of the mixes and to decrease the level of environmental pollution (Mohammad et al., 2000).

In 1960's, the engineer Charles McDonald initiated the studies on the granulated rubber incorporation to the conventional binders, called as asphalt-rubber. The method of manufacture of the asphalt-rubber was patented and known as McDonald process or wet process (Way, 2000).

The crumb rubber recycled from ground tires, used as modifier binder, is obtained by two processes, called ambient process and cryogenic process. As the name implies, ambient grinding/granulating involves tearing and shearing at room temperature. The ambient process consists of a series of crackermills or granulators, screeners, conveyors, and various types of magnets to remove steel as necessary. The crackermill process is currently the most common and productive method of producing CRM. The granulator produces a cubical, more uniformly shaped particle with lower surface area. Cryogenic grinding (or separation) is accomplished at extremely low temperatures (-87°C to -198°C) by submersing the scrap tire rubber in liquid nitrogen. Below the glass transition temperature (-620°C) the rubber is very brittle and easily fractured in a hammer mill to the desired size. Reportedly, the surface is glasslike, and thus has a much lower surface area than ambiently ground CRM of similar gradation.

Asphalt-rubber binders are obtained by the incorporation of the crumb rubber to the conventional binders under controlled temperature conditions. There are two processes for attainment of the asphalt-rubber, called as wet process and dry process. In the wet process the binder is heated the temperatures about of 190 °C, in a tank of overheating in anaerobic conditions, being carrying after that, to an appropriate tank of mixture. In this tank, the addition of the crumb rubber to the previously heated binder occurs. The digestion process, called as the bending of conventional binder with the crumb rubber, occurs in a period of 1 the 4 hours, under a temperature of 190 °C. This process of mixture is facilitated by the action of a mechanical action, generally a vane, introduced into the mixture tank (Visser & Verhaeghe, 2000).

According to Visser & Verhaeghe (2000), in the dry process, the dry granulated rubber particles first are added to the preheated mineral aggregate, before the addition of the conventional binder. The aggregate is heated to 200°C, then adds the crumb rubber to it and proceeds it the mixture for a period about 15 seconds, until a homogeneous composition. After that the addition of the conventional binder to the mixture aggregate-rubber is made by conventional processes.

Several authors (Nourelhuda et al. (2000), Sousa et al. (2000), etc) had studied the behavior of asphalt-rubber hot mixes, with crumb rubber content of up to 20%. The results have shown that the asphalt-rubber hot mixes presented major resistance to fatigue and cracking propagation than the conventional asphalt hot mixes.

3. MATERIALS

Crumb rubber and a conventional asphalt binder with 35/50 of penetration were used to produce modified asphalt-rubber binder using the wet process. The crumb rubber was recycled from ground tires using the ambient process. Approximately 20% of the tires were tire trucks of different types and origins. Samples of the granulated rubber were supplied with the following sizes:

- R_1: size of particles 0,5 – 1,15 mm;
- R_2: size of particles 1,0 – 2,0 mm;
- R_3: size of particles 2,0 – 3,0 mm;
- R_4 (35% of R_1 + 65% of R_2): size of particles 0,5 – 2,0 mm.

Grain size distribution curves for the crumb rubber samples are shown in Figure 1. Limit curves specified for crumb rubber used in the asphalt-rubber by ADOT (Arizona Department of Transportation) are also included in the figure for reference.

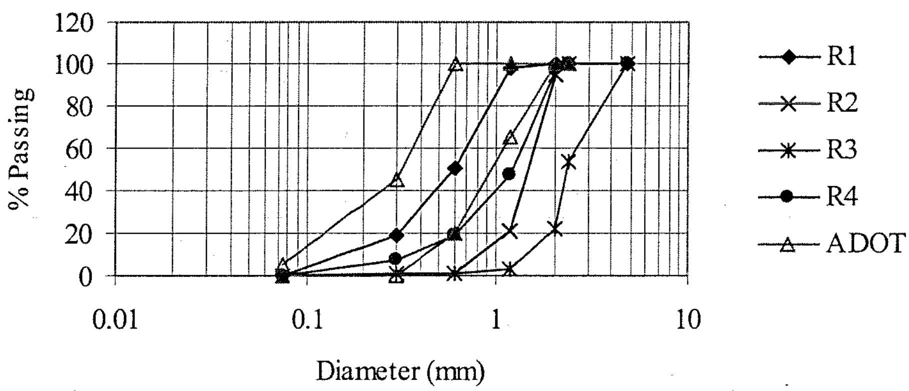

Figure 1: Grain size distribution curves for crumb rubber samples

Results of conventional characterization tests for the straight binder 35/50 are shown in Table 1. The straight binder had negligible resilience (ASTM D 5329).

Table 1: Characterization of the binder 35/50

PROPERTIES	35/50
Penetration, ASTM D 5-95 (1/10 mm)	37,9
Softening point, ASTM D36-97 (ºC)	50,0
Viscosity Brookfield at 175ºC, ASTM D 4402-87 (cP)	112,5

Granitic aggregate, called as 11/16, 4/11 and 0/4 and a recovered filler were used for the production of asphalt-rubber hot mixes. A gap-graded curve, as specified by the Department of Transport of Arizona (ADOT), was adopted for the hot mixes. Figure 2 presents the grain size distribution curve of the designed mix, as well as the limits specified by ADOT.

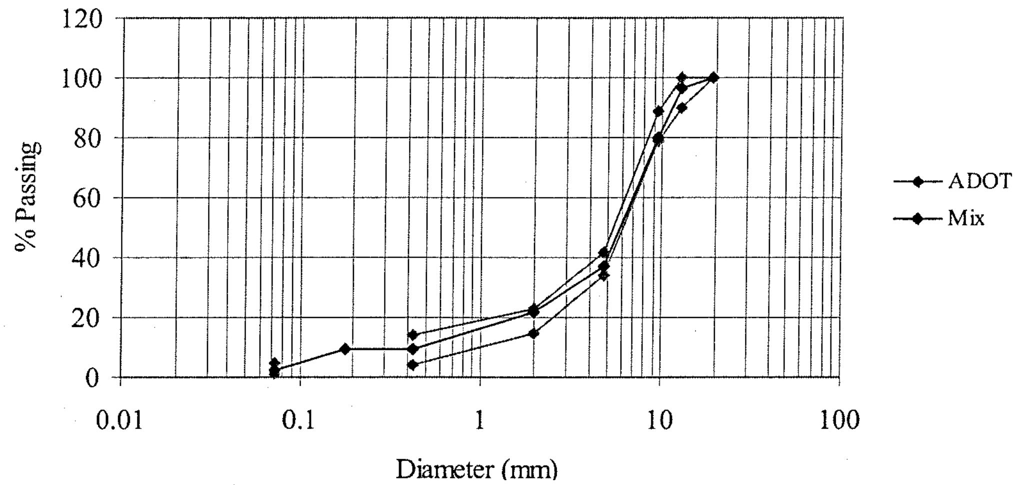

Figure 2: Grain size distribution curve for gap-graded mix

4. ASPHALT-RUBBER BINDER TESTS AND RESULTS

Two combinations of asphalt cement and crumb rubber were used as following:

- Asphalt cement 35/50 + crumb rubber R_1, referred as C_1;
- Asphalt cement 35/50 + crumb rubber R_4, referred as C_2.

For each combination presented above, the following variables and values were studied in the production of the asphalt rubber binder:

- Content of crumb rubber (% of asphalt cement weight): 10, 15, 17, 19, 21, 23 and 25;
- Digestion time (minutes): 15, 30, 45, 60, 75, 90, 120, 135, 150, 165 and 180;
- Digestion temperature (°C): 170, 190, and 210.

The properties of the produced asphalt rubber were evaluated using the usual characterization tests:

- Penetration (ASTM D 5-97);
- Softening point (ASTM D 36-95);
- Resilience (ASTM D 5329);
- Apparent viscosity (ASTM D 4402-87).

4.1. Influence of crumb rubber content on combination C_2

Figures 3, 4 and 5 present the results obtained for the physical properties of the asphalt-rubber binder with C_2 (35/50 binder and the R_4 crumb rubber), in function of the crumb rubber content and the digestion time, for a reaction temperature of 170°C, 190°C and 210°C, respectively.

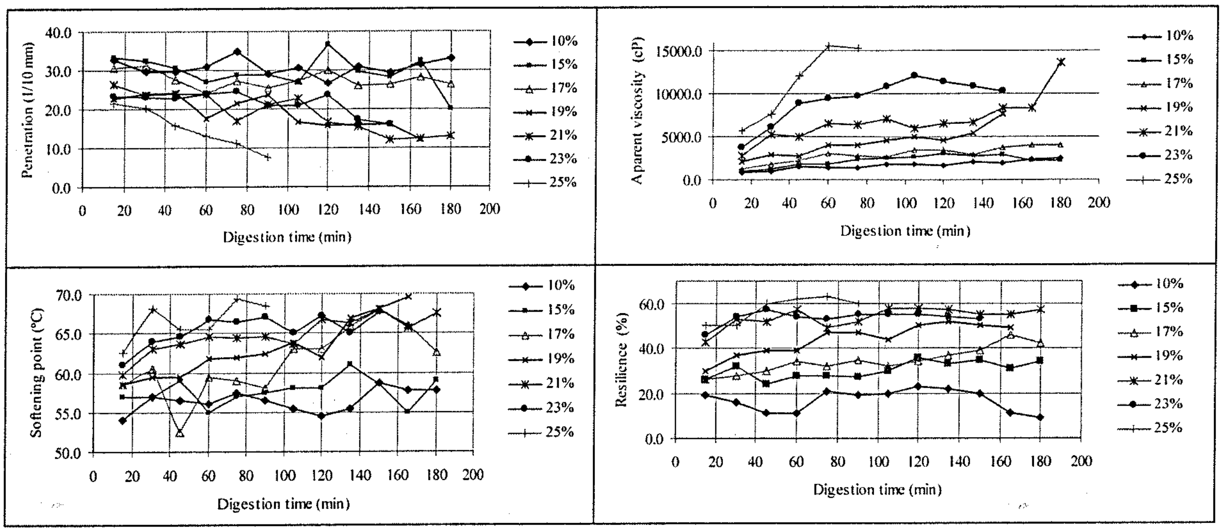

Figure 3: Penetration, viscosity Brookfield, softening point and resilience for C_2 produced at 170°C

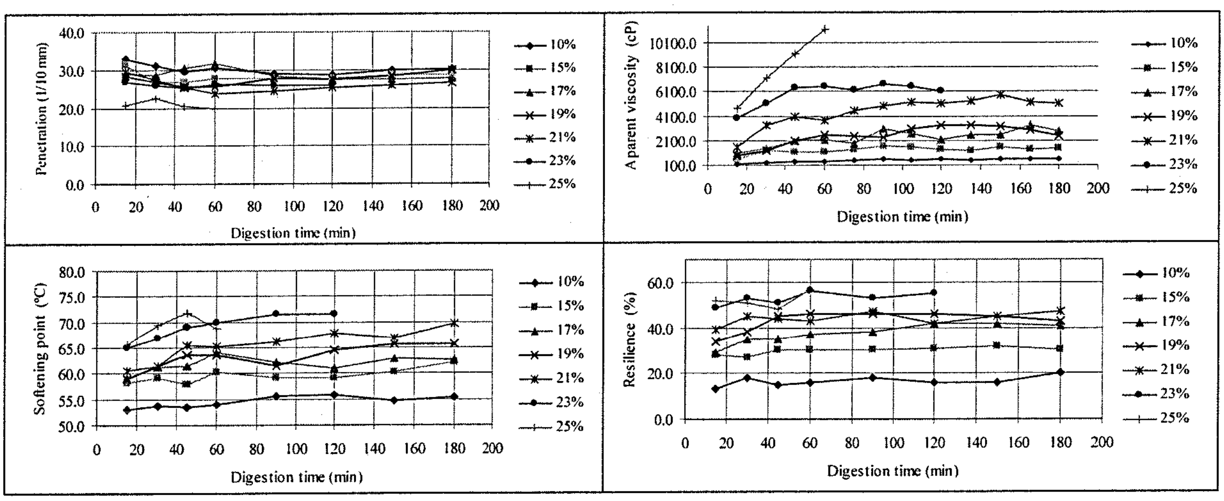

Figure 4: Penetration, viscosity Brookfield, softening point and resilience for C_2 produced at 190°C

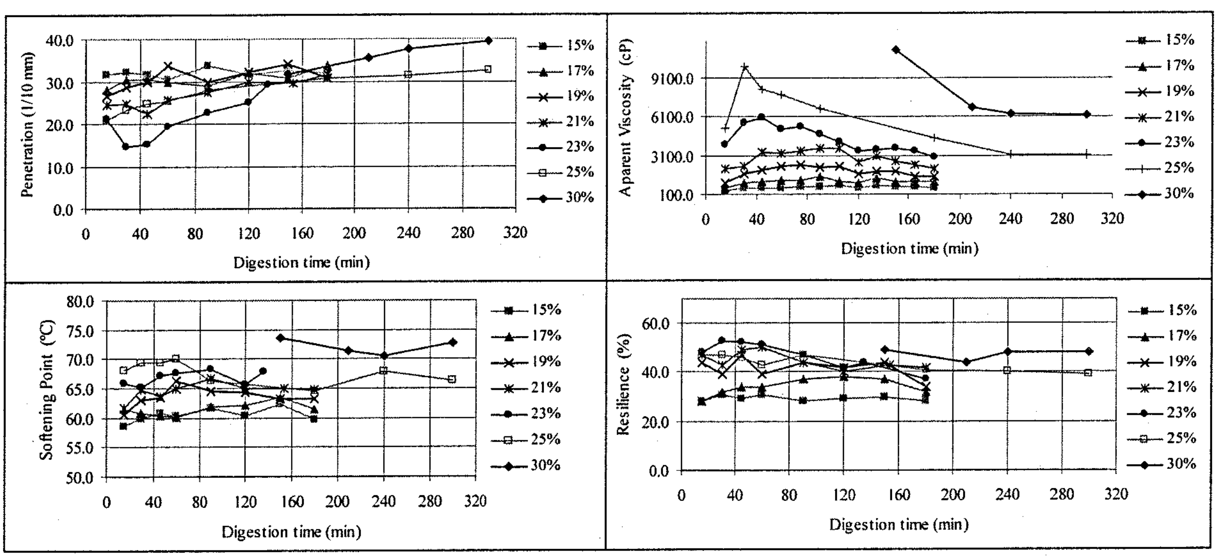

Figure 5: Penetration, viscosity Brookfield, softening point and resilience for C_2 produced at 210°C

For the temperature of 170°C and 190°C and crumb rubber contents up to 19%, the asphalt--rubber presented very high Brookfield viscosity, for periods of digestion time greater than 45 minutes. For these digestion temperatures, Brookfield viscosity of the asphalt-rubber with crumb rubber contents greater than 19% increases with the digestion time. Values of Brookfield viscosity below 8000 cP are considered satisfactory for asphalt rubber mixes production, therefore the binders still present capacity of pumping for the existing equipment in the producing plants of asphalt mixtures.

For digestion temperature of 210°C, the results obtained with the C_2 indicate that for crumb rubber contents with 19% the viscosity initially increases until a digestion time of 90 minutes, and later decreases to the end of the digestion time (300 minutes). This phenomenon can be observed in the results of the Brookfield viscosity tests carried out with the asphalt-rubber with crumb rubber contents of 19%, 23% and 25%, presented in Figure 5.

With the increase of the digestion time it was possible to get asphalt-rubber with 30% of the R_4 crumb rubber, for the binder 35/50, with a digestion temperature of 210°C and values of Brookfield viscosity of approximately 600 cP. Figure 5 shows that to the asphalt-rubber binders with crumb rubber content of 30%, although with the reduction of Brookfield viscosity to the end of the period of digestion of 300 minutes occurs values obtained for the resilience was approximately 45%. This value is higher than values of all the samples obtained previously.

This reduction in viscosity for high digestion times occurred only for the digestion temperature of 210°C, and it was not observed for the temperatures of 170°C and 190°C. It was observed that together with the reduction of Brookfield viscosity in high digestion times occurred a reduction in the softening point and in the resilience of the collected samples, as shown in Figure 5. The results obtained in the penetration tests in all the cases are not conclusive in terms of the influence of crumb rubber content, digestion temperature and time. It seems reasonable to condemn this test in this type of binders, because the scale factor existing between the dimension of the used needle and the size of existing rubber particles in the asphalt-rubber.

4.2. Influence of crumb rubber contents on C_1

Figures 6 presents the results obtained for the physical properties of the asphalt-rubber binders obtained with C_1 (35/50 binder and the R_1 crumb rubber), in function of the crumb rubber content and the digestion time, for a reaction temperature of 170°C.

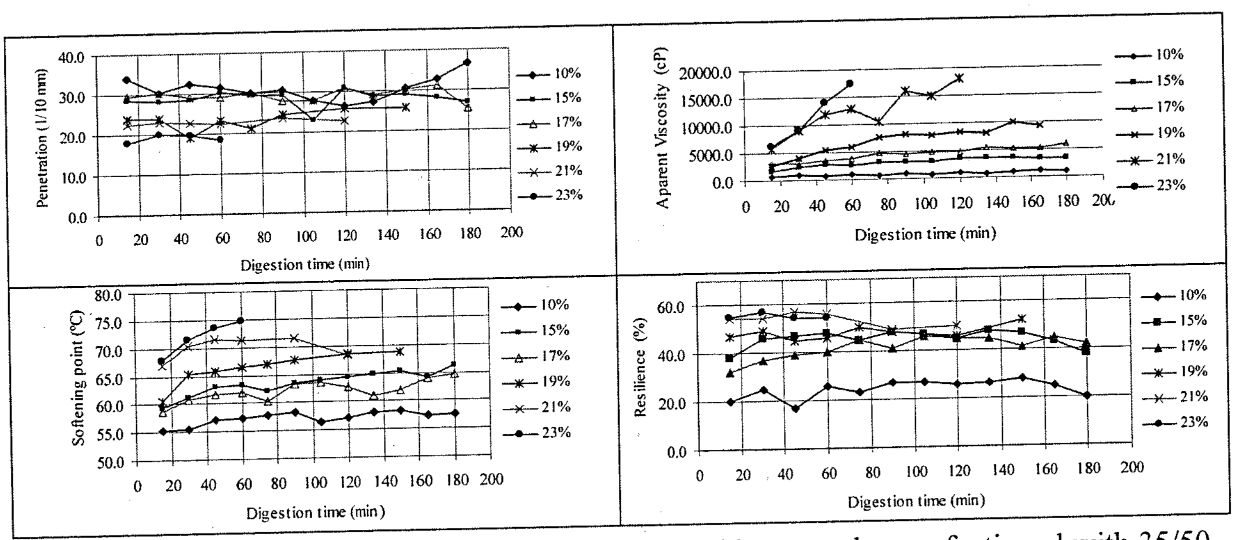

Figure 6: Softening point and resilience in asphalt-rubber samples confectioned with 35/50 binder and R_1 crumb rubber for temperature of digestion of 170°C

The results of the tests carried out in asphalt-rubber binder for combination C_1 (35/50 binder and the R_1 crumb rubber) presented in Figures 6, indicate that the influence of the crumb rubber content in the properties of the asphalt-rubber is similar to the one observed for the asphalt-rubber with the R_4 crumb rubber.

4.3. Influence of crumb rubber gradation

Figure 7 present the comparison between the physical properties of the asphalt-rubber obtained with the crumb rubber R_1 and the crumb rubber R_2 for 35/50 binder, the reaction temperature of 170°C and crumb rubber content of 19% as function of the digestion time.

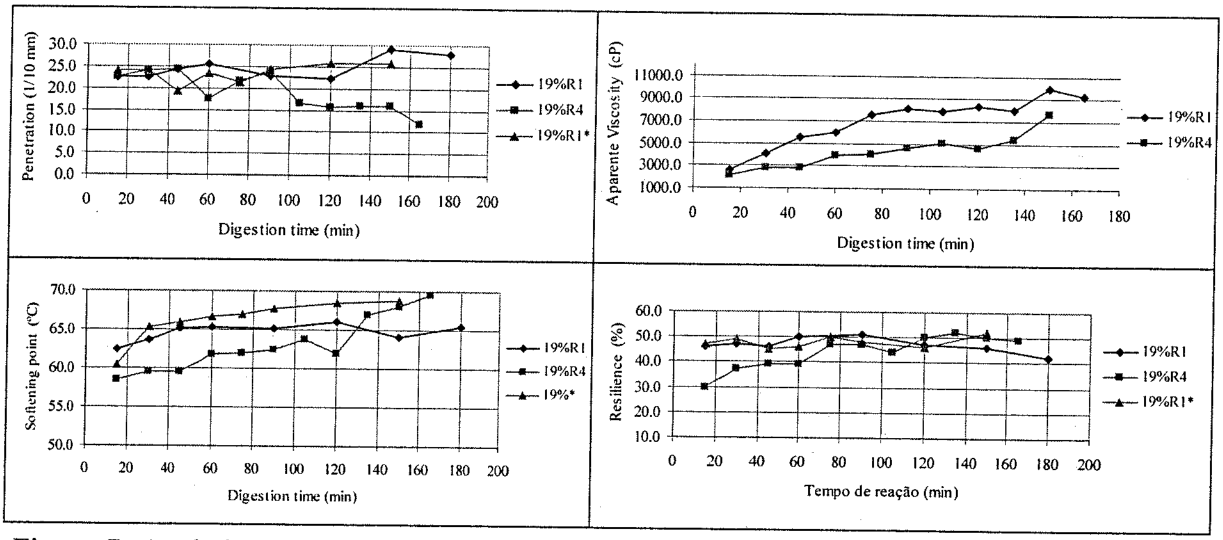

Figure 7: Asphalt rubber properties with binder 35/50 for 19% of crumb rubbers R_1 and R_4, for the temperature of digestion of 170°C

The comparison between the asphalt-rubber obtained with the binder 35/50 and the crumb rubbers R_1 and R_4 for a crumb rubber content 19% it was concluded that the reduction of the crumb rubber size increases Brookfield viscosity, the softening point and resilience. This can be explained by the fact that the use of a crumb rubber with fine grading increases the specific surface of the material, and, therefore a more reaction of the crumb rubber with binder exists.

4.4. Mechanical performance of asphalt-rubber hot mixes

Based on the results of the study of the crumb rubber gradation, crumb rubber content, digestion time and production temperature on the asphalt rubber binder properties, namely penetration, softening point, viscosity and resilience, two binders were selected:

- BMB1: asphalt-rubber with 35/50 asphalt cement, crumb rubber R_4, crumb rubber content of 21%, digestion time of 300 minutes and reaction temperature of 210°C;
- BMB2: asphalt-rubber with 35/50 asphalt cement, crumb rubber R_4, crumb rubber content of 25%, digestion time of 300 minutes and reaction temperature of 210°C.

In the following are presented stiffness and fatigue test results of the asphalt hot mixes confectioned with asphalt-rubber, resultant of the combination of the R_4 crumb rubber and binder 35/50.

The values adopted for the temperatures of the binder were of 170°C, for aggregates and compacting of the mixture had been of 190°C and 164°C, respectively. These temperatures were chosen taking into account the capability to flow of the asphalt-rubber produced and the experience of constructors in the application of this type of mixture.

The results obtained in the mix design using Marshall method were not conclusive regarding the ideal binder content for each one of the mixtures produced with the asphalt-rubber BMB 1 and BMB 2. Therefore, it was adopted for asphalt-rubber hot mix a binder content of 8% in relation to the all up weight of the mixture. This value is very closed to the values normally used in the production of mixtures with asphalt-rubber. It was produced two different mixtures gap graded, both with void content of 10%.

The stiffness modulus and fatigue tests were carried out under controlled deformation in prismatic specimen in form of beam with the following dimensions: 381 ± 6,35 mm length, 50,8 ± 6,35 mm height and 63,5 ± 6,35 mm width. The tests were carried out under temperature of 20°C and to fatigue tests the frequency employed had been of 10Hz.

Figure 8 presents the variation of the values of the stiffness modulus in function of the frequency of applied loads, for the mixtures produced with the binders BMB 1 and BMB 2 with void content of 10%. Figures 9 presents the curve of fatigue life for the mixtures with asphalt-rubber studied versus the tensile strain produced in the specimen.

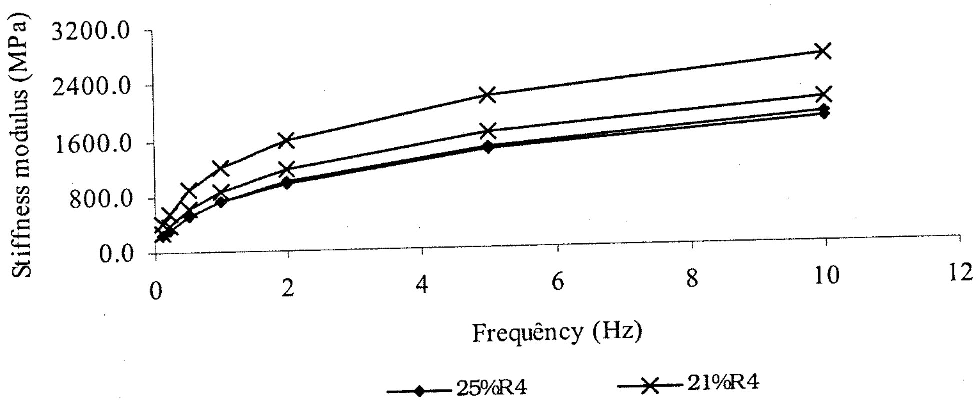

Figure 8: Stiffness modulus of asphalt-rubber hot mixes

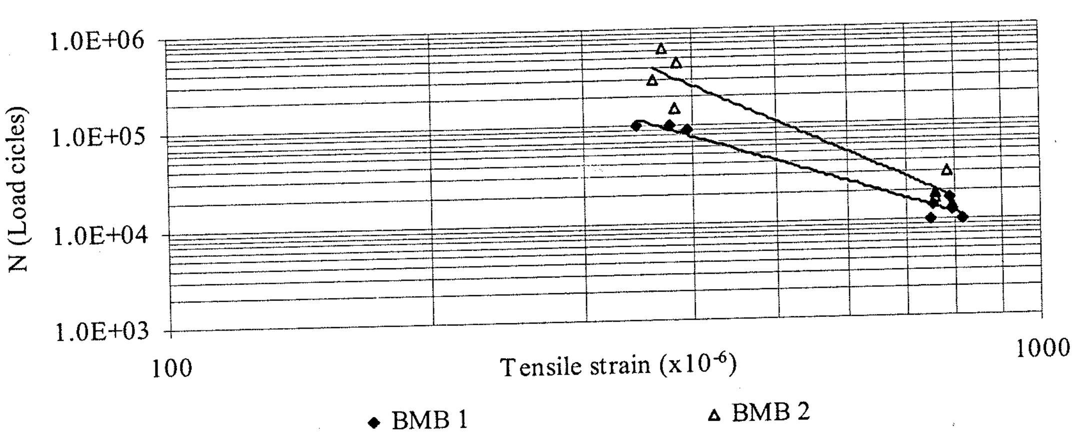

Figure 9: Fatigue life of the mixtures confectioned with asphalt-rubber BMB 4125300210 and BMB 4125300210 versus tension strain

The results obtained for the mixtures confectioned with asphalt-rubber showed that the increase of the crumb rubber content of 21% to 25% presented as consequence the reduction of the stiffness modulus and the increase of the fatigue life. These results of mechanical performance need to be complemented with permanent deformations, tension and resistance to cracking propagation tests so that one can know fully the performance of these mixtures with high crumb rubber content.

5. CONCLUSIONS

The results presented in this work indicate in a general way that the increase in rubber content in the binders modified with crumb rubber recycled from ground tires produces an increase the Brookfield viscosity, the softening point and the resilience, for any temperature and used time of digestion.

The production of asphalt-rubber with high crumb rubber contents, specifically values superior to 21%, is conditioned to grading size of the crumb rubber, temperature and time of digestion. For the temperature of digestion of 170°C and 190°C the Brookfield viscosity of the asphalt-rubber increased with the digestion time, for all the crumb rubber contents and grading size studied. For the temperature of digestion of 210°C, with crumb rubber content up to 21%, for the R_4 crumb rubber, the asphalt-rubber resultants presented an increase of Brookfield viscosity, and after a time of digestion of approximately 300 minutes, this viscosity came back to decrease. With this phenomenon had been produced asphalt-rubber samples with crumb rubber content of 30%, with Brookfield viscosity of approximately 6000 cP.

The use of crumb rubber recycled from ground tires with finer grading size increase of Brookfield viscosity, penetration, resilience and softening for crumb rubber content of 19%. This increase of viscosity occurs for the biggest specific surface of the rubber, which makes with that it has a bigger reaction with the used conventional binder, and also a bigger absorption of yours aromatic oils.

The incorporated crumb rubber content to the binder affects the results gotten in the stiffness modulus and fatigue tests. Mixtures confectioned with the same characteristics, but with binders that present different incorporated crumb rubber contents had presented significant differences. The increase of the crumb rubber content induces an increase in the fatigue life of the asphalt mixes and a reduction of the stiffness modulus. In this work they had not been presented the results of fatigue and stiffness modulus tests of mixtures produced with conventional binders, for the fact of that it is a proven fact that the asphalt-rubber hot mixes present a fatigue life superior the conventional mixes. Therefore, it was only intended to show the behavior of mixtures with high crumb rubber contents, in comparison with those confectioned with crumb rubber content of even 21%.

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