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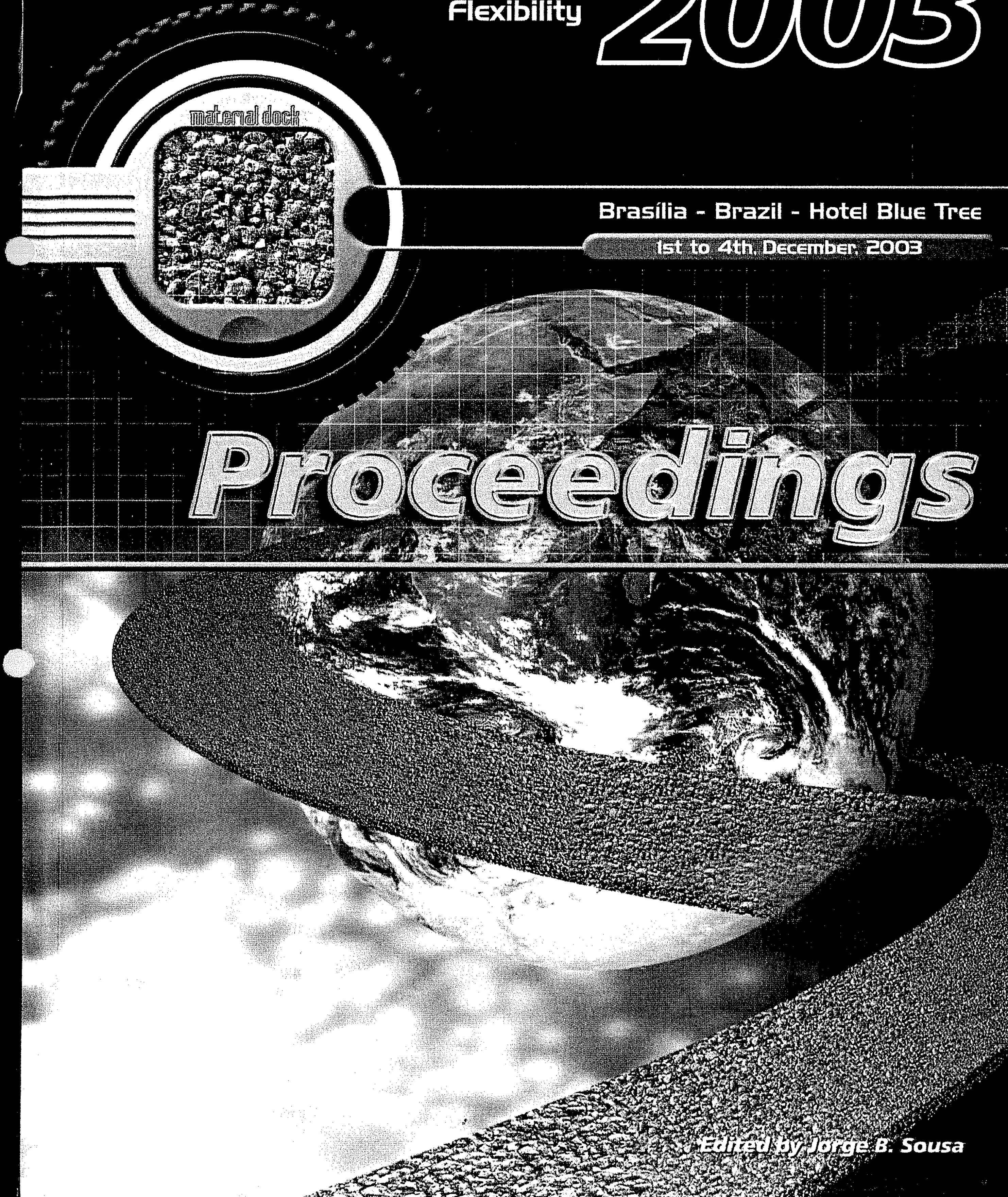

Proceedings

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PROPERTIES OF ASPHALT-RUBBER BINDERS RELATED TO CHARACTERISTICS OF THE INCORPORATED CRUMB RUBBER

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ABSTRACT: The behavior of asphalt binders modified with recycled crumb rubber depends on several factors, such as: rubber contents and type, temperature and time employed during the digestion process. This paper shows the results of a series of tests performed on asphalt-rubber produced via the wet process. The tests included standard penetration, softening point, Brookfield viscosity and resilience. The results show that the limiting variable in the digestion process is the Brookfield viscosity. The influence of rubber type occurred especially in terms of Brookfield viscosity and softening point. There was a decrease in these properties for the asphalt-rubber binders produced with crumb rubber obtained by cryogenic process. Besides, the results show improvements in the modified binders properties, in terms of softening and resilience, when higher rubber content, temperature and digestion time are used.

KEY WORDS: asphalt-rubber, recycled rubber, asphalt binders

1. Introduction

Several researches are constantly carried out in the quest for finding materials that could enhance the properties of asphalt mixes, thus reducing road maintenance costs. Addition of polymers has become common practice in several countries, with the main objective of improving flexibility and thermal susceptibility of modified asphalt binders. However, that inevitably adds to the final cost of the product.

Besides performance improvements, there are increasing concerns about developing environment friendly products. In this context, there is growing interest for asphalts modified with crumb rubber recycled from used tires, also known as asphalt-rubber or rubber-asphalt. This material constitutes an important source of consumption for a huge mass of used tires produced annually. According to the Brazilian Association of Pneumatic Industry, Brazil produces 45 million units of tires annually and about 30 million used units are discarded annually. That represents approximately 180.000 tons of rubber, which is approximately 10% of the national annual asphalt production. It is usual to incorporate 20% of rubber in weight to produce asphalt-rubber. Therefore, this solution may give a proper destine to the whole mass of used tires produced annually in Brazil.

The rubber used to produce tires comprises a mixture of different components, such as, styrene-butadiene rubber of high molecular weight, natural rubber, polymers, thermoplastic elastomers and carbon particles, among others [HOR 00]. The rich diversity of polymers enhances the properties of conventional asphalt binders, when crumb rubber is incorporated to them.

The behavior of modified asphalt-rubbers depends on several factors, such as, the origin, fabrication process and grain size distribution of the crumb rubber, the type of base conventional binder used in the mixture, besides the temperature and time of the mixing process or digestion. Several authors have investigated the rheological and physical properties of binders modified with rubber, for rubber contents below 20% in weight [AND 00].

The present work investigates the influence of rubber type and content in the physical properties of asphalt-rubber binders produced. Conventional base binder having a penetration grade of 50/70 was mixed with crumb rubber produced via milling at ambient temperature for different rubber contents and via cryogenic process. The mixtures, produced using the wet process, were subjected to conventional tests, such as, penetration, softening point, Brookfield viscosity and resilience.

2. Objetives

The objective of the present work is to investigate the main characteristics of crumb rubber that affect the physical properties of modified binders. The principal factors studied were the crumb rubber type and contents incorporated to conventional base binder.

3. Literature Review

Rubbers used in the production of tires have different constituents, but the main component is vulcanized rubber. During the vulcanization process, rubber is heated in the presence of sulphur and activating and accelerating agents. This process produces cross-links in the individual molecules of polymers, which confers to the rubber a rigid three-dimensional structure. The strength of the rubber is proportional to the number of such links [SAR 81].

The constituents of passenger vehicle tires are shown in Figure 1:

a) Tread: tire part which is directly in contact with the pavement, its composition (rubber and special chemical agents) provides great wear resistance;

b) Belts: usually made from steel, the belts are used to reinforce the area under the tread. These belts provide puncture resistance and help the tyre stay flat so that it makes the best contact with the road;

c) Polyester Carcass: composed of nylon or polyester cords, provides mechanical resistance to the tire;

d) Sidewall: The sidewall provides lateral stability for the tyre, protects the body plies and helps keep the air from escaping;

e) The Bead Bundle: The bead is a loop of high-strength, steel cable coated with rubber. It gives the tire the strength it needs to stay seated on the wheel rim.

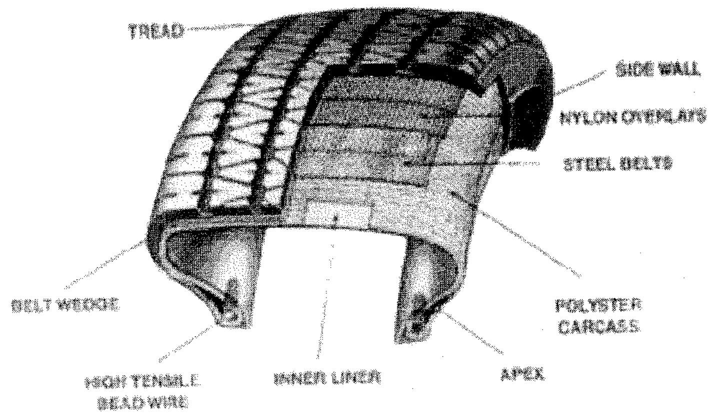

Figure 1. *Components of the tire*

A passenger vehicle tire is approximately made of 85% of rubber and 15% of steel fibers and polyester carcass. After its lifetime usage the rubber percentage in a tire will still be 83%, and the steel fibers quantities will be unaltered. [SEV 02]. On the other hand, the truck tires are composed with greater percentages of rubber, mainly, natural rubber. This difference will affect the mechanical behavior of rubber asphalts produced from either trucks or passengers' vehicle tires.

Grinding, or cryogenic processes can be used to produce the crumb rubber that will be incorporated in the rubber asphalt. The grinding process is basically tearing and crushing the old tires at the ambient temperature. A combination of grinders or granulators followed by sieves, transport conveyers and different kinds of magnets are used to crush and extract the steel of the carcass. The grinding process method has been widely adopted and is also more productive to obtain the crumb rubber. The final product is generally an irregular particle, with high specific surface. When working with granulators, more regular particles with lower specific surface can be obtained.

The cryogenic process is carried at very low temperatures (-87°C to –198°C). In this case, the rubber of the tires is dipped into liquid nitrogen. At very low temperatures, the rubber becomes very brittle and it can be easily pulled apart on a press, into the desired particles dimension. These particles of crumb rubber have lower specific surface than the ones obtained by the grinding process.

The use of binders modified with rubber started in the decade of 1940 [MOH 00]. However, only in the decade of 1960 the process of manufacturing asphalt-rubber, known as wet process or McDonald process, was developed and patented by Engineer Charles McDonald. From 1964, the Arizona Department of Transportation (ADOT) started using binders modified with crumb rubber in several maintenance works and in the production of asphalt hot mixes [WAY 00].

There are two processes for producing asphalt-rubber, known as the wet process and the dry process. In the wet process, a straight binder is initially preheated up to temperatures around 190oC in a tank under hermetic conditions and then transported to a blending tank, where crumb rubber is added. The digestion process, which is the incorporation of rubber by the conventional binder, continues for a period of 1 to 4 hours, under a temperature of 190oC. The process is facilitated by the mechanical agitation produced by a horizontal shaft [VIS 00]. The values of temperature and time of digestion described above are not standardized and vary according to production capacity and available equipments.

In the dry process, particles of crumb rubber are added to preheated mineral aggregates, before the addition of the straight bituminous binder [VIS 00]. Aggregates are heated to temperatures of approximately 200oC, then crumb rubber is added and mixed for about 15 seconds until a homogeneous mixture is obtained. Straight binder is then added in a conventional mixing plant.

In the dry process, modified mixes rather than modified binders are produced, since there is no digestion of the rubber by the conventional binder. The time of contact between the rubber and the binder, in the dry process, is relatively short and not enough to produce all necessary reactions between the two materials [HOR 00] [OLI 00].

Physical properties of asphalt binders are generally expressed in terms of penetration grade, softening point, thermal susceptibility, viscosity and ductility, among others. Previous studies with asphalt-rubbers, incorporating up to 20% of crumb rubber in weight, have demonstrated that there is an increase in viscosity in comparison with conventional binders [AND 00]. Other studies [SEB 00] show that the incorporation of rubber into asphalt binders enhances their viscoelastic properties.

4. ReferencesMaterials

Crumb rubbers, recycled from unserviceable tires using the ambient grinding and the cryogenic processes were used in this work. Approximately 20% of the tires were from trucks and the remaining 80% from passenger vehicles of different types and origins. The following grain sizes of crumb rubber modifiers were tested:

- CRM1: particle diameter between 0,5 – 2,0 mm from ambient grinding process;
- CRM2: particle diameter between 0,5 – 2,0 mm from cryogenic process.

Figure 1 shows the grain size distribution curves for the two rubber types described in Table 1. The grade envelope, prescribed by ADOT for crumb rubber to be used in the production of asphalt-rubber, is also shown in the figures.

Table 1. *Grain size distributions*

Sieve size		% Passing			
inch	mm	ADOT		R1	R2
N° 4	4,75	100	100	100	100
N° 8	2,36	100	100	100	100
N° 10	2,00	100	100	100	97,3
N° 16	1,18	65	100	97,5	49,7
N° 30	0,60	20	100	50,6	24,6
N° 50	0,30	0	45	19,4	4,1
N°200	0,075	0	5	0	0

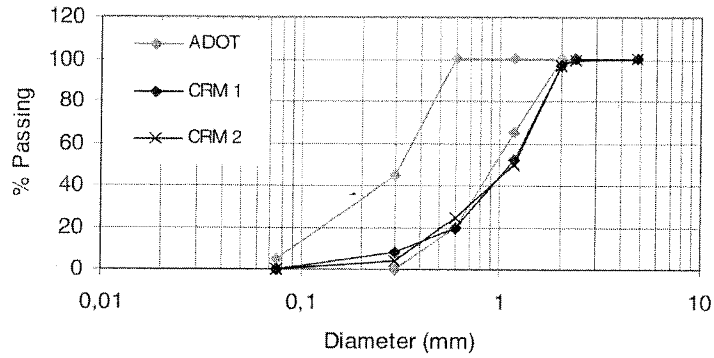

Figure 1. *Grain size distribution curves for CRM1 and CRM2*

A penetration grade of 50/70 straight asphalt was used to mix with the crumb rubbers previously described. Table 2 presents the results of standard characterization tests preformed for the conventional binder.

Table 2. *Characterization of the conventional binder*

PHYSICAL PROPERTIES	**50/70**
Penetration, ASTM D 5-95 (1/10 mm)	52,0
Softening point, ASTM D36-97 (ºC)	50,6
Brookfield viscosity at 175ºC, ASTM D 4402-87 (cP)	87,5
Resilience, ASTM D5329 (%)	14,0

5. Asphalt-rubber: production, tests, results and discussion

5.1. Production of different types of asphalt-rubber and testing methods

The following straight binder and crumb rubber combinations were used to produce asphalt rubber using the wet process:

- Combination C1: binder AC 50/70 + CRM1;
- Combination C2: binder AC 50/70 + CRM2;

For the combination C1 above, the following combinations of production variables were also investigated:

- Rubber content (% of total weight): 10, 15, 17, 19, 21, 23, 25 and 30;
- Digestion time (minutes): 15, 30, 45, 60, 120, 180, 240 and 300;
- Temperature of digestion (ºC): 190.

The influence of rubber type (cryogenic or ambient process) was investigated by comparing asphalt rubber combinations C1 and C2 for a crumb rubber content of 21%

in weight and digestion temperature of 190ºC.

The following tests were performed to study the physical properties of the asphalt-rubbers produced for this research:

- Penetration (ASTM D5);
- Softening point (ASTM D36);
- Resilience (ASTM D5329);
- Apparent Brookfield viscosity (ASTM D2196).

The tests described above were chosen, since they are currently used for the characterization of asphalt binders in laboratories all over the world. The resilience test, normalized by ASTM D5329, measures the elastic recovery of samples of modified binders under compression. Brookfield viscosity test seems to be the most convenient to define the flow properties of binders modified with rubber under high temperatures. The presence of particles of rubber makes it impossible to measure asphalt-rubber viscosity with most conventional viscosity apparatus currently available.

The specified configurations used in this research were designed to investigate each important variable that may interfere in the properties of the produced asphalt-rubbers. Figure 2 shows the equipments used in the production of asphalt-rubber binders. These comprise an oven, equipped with temperature control, and an assembly of engine and paddle that facilitates the mixture between the conventional binder and the crumb rubber. Table 3 presents the target values specified in the norm ASTM D0114-97 for asphalt binders modified with crumb rubber recycled from unserviceable tires.

Table 3. *Target physical properties of asphalt-rubber (ASTM D0114-97)*

PHYSICAL PROPERTY	UNIT	RANGE
Apparent Brookfield viscosity, 175°C (ASTM D2196)	cP	1500 - 5000
Penetration, 25°C, 100g, 5s (ASTM D5)	1/10 mm	25-75
Softening point (ASTM D36)	°C	> 57,2
Resilience, 25°C (ASTM D5329)	%	> 25

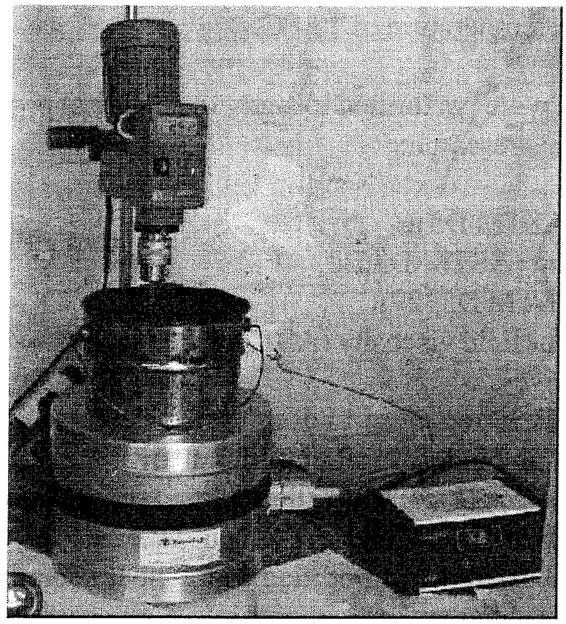

Figure 2. *Equipment used for the production of asphalt-rubber binders*

5.2. Influence of the rubber content in the physical properties of asphalt-rubber

In order to investigate the influence of the rubber content on the physical properties of asphalt-rubber, the results of tests performed with combination C1 will be discussed. Figures 3 to 6 show the results of penetration, Brookfield viscosity, softening point and resilience for asphalt-rubber C1 produced for different digestion times and rubber contents at a constant temperature of 190oC. In the same figures, the results for samples of straight binder AC 50/70, collected at different times, are also shown for comparison.

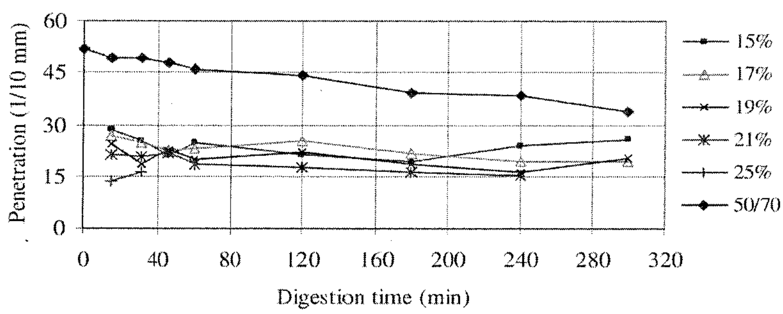

Figure 3. *Penetration of samples of asphalt-rubber combination C1, for a digestion temperature of 190ºC*

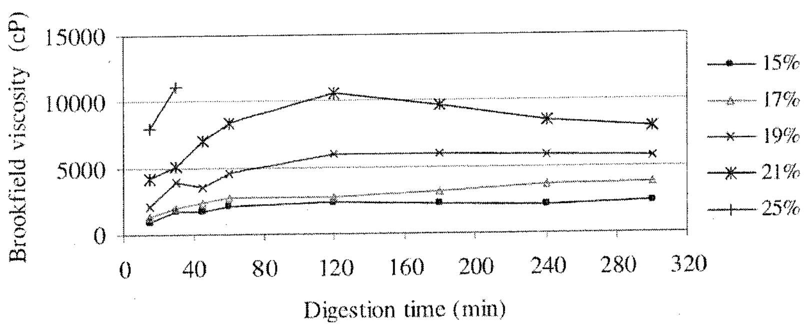

Figure 4. *Brookfield viscosity at 190ºC of samples of asphalt-rubber combination C1, for a digestion temperature of 190ºC*

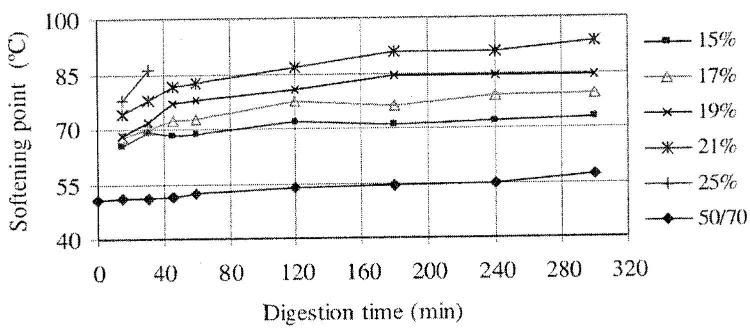

Figure 5. *Softening point of samples of asphalt-rubber combination C1, for a digestion temperature of 190ºC*

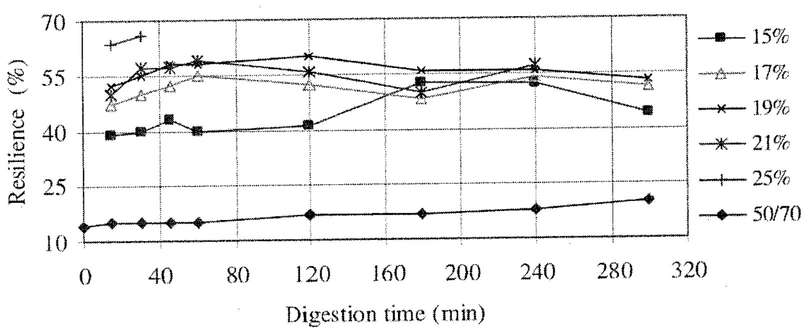

Figure 6. *Resilience of samples of asphalt-rubber combination C1, for a digestion temperature of 190ºC*

The results of tests with the straight binder AC 50/70 show a gradual decrease in values of penetration grade and an increase in softening point for samples collected at different times at the same temperature, as observed in Figures 3 and 5, respectively. These results indicate that aging of the conventional binder is taking place due to the volatilization of light fractions. The evaporation of these light components, controlled by the temperature, is one of the primary mechanisms of aging in asphalt binders [EPP 97].

The penetration results, shown in Figure 3, do not allow definitive conclusions as to the influence of digestion time and rubber content on this property. The results present a significant scattering and are highly dependent on the superficial distribution of crumb rubber grains in the tested samples. Anyhow, it is clear that the incorporation of crumb rubber decreases the penetration grade with respect to that of the conventional binder.

As to the Brookfield viscosity at 190oC, the results in Figure 4 clearly show an increase in viscosity for higher rubber contents. For rubber contents up to 19%, there is an increase in viscosity with digestion time up to 60 minutes and this property remains almost constant thereafter. For higher rubber contents, however, there seems to be a trend of initial viscosity increase followed by viscosity loss after a certain time of digestion around 120 minutes, leading to a constant value in the long term.

A model of interaction between rubber particles and asphalt may give some clue to understanding the viscosity behavior [HOL 00]. According to this model the asphaltenes and light fractions of the conventional asphalt binder and the rubber particles interact to form a gel coated particle. The rubber particles swell in a process similar to what occurs in polymer asphalt systems. The large increase in viscosity over 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 over time.

The results of softening point in Figure 5 clearly show a significant gain in the softening point for increasing quantities of incorporated crumb rubber. This process of increase in softening point is also influenced by the digestion time. There seems to be a gradual increase in softening point in the early times of digestion up to 60 minutes. This gain becomes less evident thereafter. The digestion process and interaction between the rubber grains may create a three-dimensional structure, which is more resistant to external forces at a given temperature. The structure, initially formed by the binder and the individual rubber particles, becomes more stable as the modified grains melt together in the early stages of the reaction. The grain size distribution of the crumb rubber used here may facilitate the creation of these bonds.

The results of resilience, shown in Figure 6, also show a gain in the modified binder elasticity for increasing rubber contents. This gain is more noticeable in the first 60 minutes of digestion time and remains practically constant thereafter. The high elasticity of the rubber particles is somehow incorporated into the modified rubber. The results of resilience, as well as those of softening point, help to corroborate it the idea that asphalt-rubbers have a better three-dimensional structure, which responds for its higher elasticity.

5.3. *Influence of the type of rubber in the physical properties of asphalt-rubber*

Figures 7 to 10 present the results of physical properties of asphalt-rubber obtained from the blending of conventional binder AC 50/70 and crumb rubbers produced according to different processes: rubber CRM1 produced with ambient grinding and rubber CRM2, produced with the cryogenic process. A percentage of 21% of rubber in weight was incorporated into the conventional binder and the mixture produced at a digestion temperature of 190oC.

The results in Figures 8 and 9 show that the use of crumb rubbers obtained with the cryogenic process produced modified asphalt-rubbers with lower Brookfield viscosity and lower softening points. No significant change of penetration and resilience was observed, irrespective to the process of fabrication of the crumb rubber used in the asphalt-rubber.

The cryogenic process produces crumb rubber with a smaller specific surface. Also these grains have a well-defined and regular shape. The grains obtained with the cryogenic process are also harder than those produced by grinding at ambient temperature.

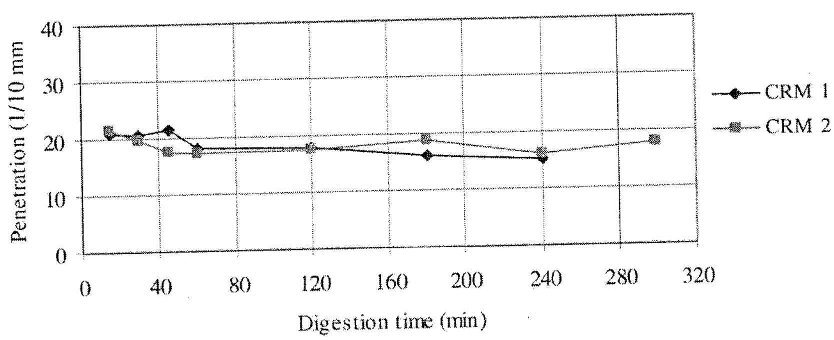

Figure 7. *Penetration of samples of asphalt-rubber combination C6, for a digestion temperature of 190ºC*

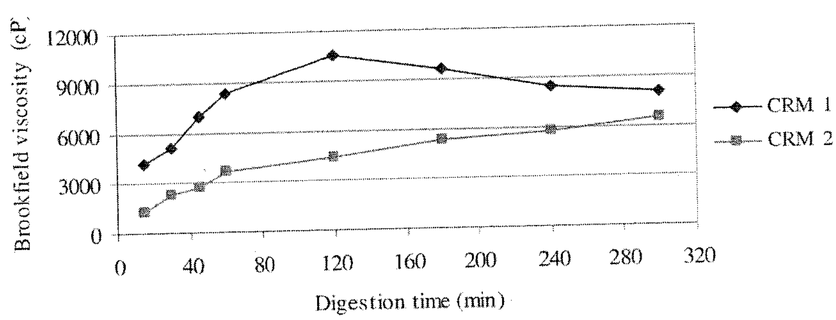

Figure 8. *Brookfield viscosity of samples of asphalt-rubber combination C6, for a digestion temperature of 190ºC*

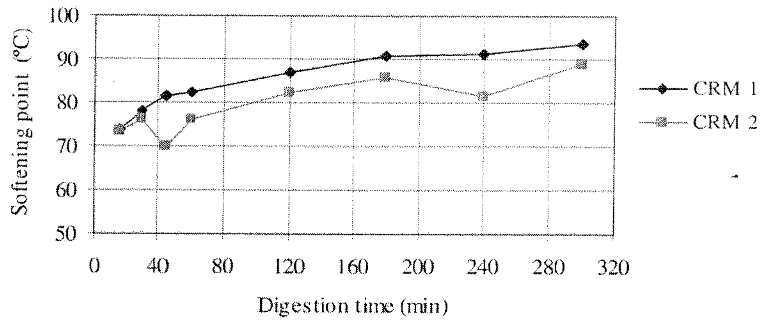

Figure 9. *Softening point of samples of asphalt-rubbe combinationC6, for a digestion temperature of 190ºC*

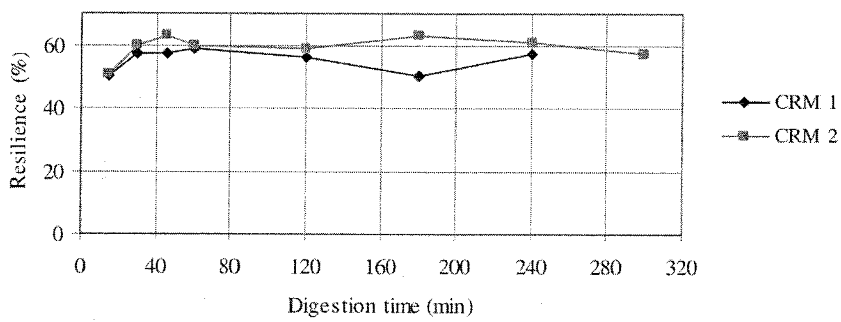

Figure 10. *Resilience of samples of asphalt-rubber combination C6, for a digestion temperature of 190ºC*

6. Conclusions

Test results for the straight binder AC 50/70 show that aging takes place with time for a given temperature. This is due to the volatilization of light fractions present in the binder.

The results of penetration test show a decrease of penetration grade with the incorporation of crumb rubber. However, this type of test is not recommended for asphalt-rubbers. Their results show a significant scattering, since they are dependent on the distribution of rubber grains on the surface of the test sample.

Higher contents of crumb rubber incorporated into the conventional binder leads to the production of modified asphalt-rubbers with higher Brookfield viscosity, higher softening point and higher resilience for all digestion times investigated.

The gain in viscosity was more prominent during the initial 60 minutes of digestion. For asphalt-rubbers incorporating up to 19% of crumb rubber in weight, this viscosity gain remained constant with increasing digestion time. For higher contents of crumb rubber, the initial viscosity gain was followed by a period of viscosity reduction and later stabilization. That seems to be related to the interaction between rubber particles and the components of the asphalt binder, which produce an unstable gel-coated particle.

In the wet process, the incorporation of crumb rubber into conventional binders helps to create a three-dimensional structure that confers higher softening temperature and higher elasticity to the modified binder.

The use of crumb rubber manufactured with the cryogenic process for the production of asphalt-rubber generates a mixture with lower viscosity and lower softening point, if compared to asphalt-rubber that incorporate rubbers produced with the grinding process at ambient temperature. Other properties, such as penetration and resilience, were not affected.

7.Acknowledgements

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8.References

[AND 00] ANDERSON J., PAMPULIM V., SAÏM R. SOUSA J.B., *"Asphalt rubber laboratory properties related to type and process technology of crumb rubber", Asphalt Rubber 2000 – Proceedings, Portugal, 2000.*

[EPP 97] EPPS A.L., *"Thermal behavior of crumb-rubber modified asphalt concrete mixtures"*, Ph. D. Thesis, University of California, Berkeley, 1997.

[HOL 00] HOLLERAN G., REED J.R., *"Emulsification of asphalt rubber blends"*, Asphalt Rubber 2000 – Proceedings, Portugal, 2000, p. 383-409.

[HOR 00] HORODECKA R., KALABINSKA M., PILAT J., RADZISZEWSKI P., SYBILSKI D., *"Utilization of scrap rubber for bitumen and asphalt concrete modification in Poland"*, Asphalt Rubber 2000 – Proceedings, Portugal, 2000, p. 273-285.

[MOH 00] MOHAMMAD L.N., HUANG B., ROBERTS F., RASOULIAN M., *"Accelerated loading performance and laboratory characterization of crumb rubber asphalt pavements"*, Asphalt Rubber 2000 – Proceedings, Portugal, 2000, p. 189-220.

[OLI 00] OLIVER J.W.H., *"Rutting and fatigue properties of crumbed rubber hot mix asphalts"*, Asphalt Rubber 2000 – Proceedings, Portugal, 2000, p. 221-240.

[SAR 81] SARDELLA A., MATHEUS E. "Dicionário de química", Editora Ática, São Paulo, Brasil, 1981.

[SEB 00] SEBAALY P.E., GOPAL V., ARDILA-COULSON M., *"Impact of crumb rubber and sand on rheological properties of binders"*, Asphalt Rubber 2000 – Proceedings, Portugal, 2000, p. 371-382.

[SEV 02] SEVERO, L.E.P., RUWER P., MORILHA JUNIOR A., DANTAS G.A. CERATTI J.A., *"Avaliação da aplicação de concreto asfáltico com ligante modificado por borracha de pneu"*, 11ª Reunião de Pavimentação Urbana, Brasil, 2002.

[VIS 00] VISSER A.T., VERHAEGHE B., *"Bitumen rubber: Lessons learned in South Africa"*, Asphalt Rubber 2000 – Proceedings, Portugal, 2000, p. 33-52.

[WAY 00] WAY G.B., *"OFGC meets CRM: where the rubber meets the rubber"*, Asphalt Rubber 2000 – Proceedings, Portugal, 2000, p. 15-32.