Universidade do Minho

[CI-62]

Fontes, L.P.T.L., Pereira, P.A.A., Trichês, G., **Pais, J.C.**, Luzia, R.

"Laboratory optimization of continuous blend asphalt rubber"

EPAM3 – 3rd European Pavement and Asset Management Conference, Coimbra, Portugal, 7-9 July, 2008

LABORATORY OPTIMIZATION OF CONTINUOUS BLEND ASPHALT RUBBER

Liseane Fontes*, Paulo Pereira**, Glicério Trichês*, Jorge Pais**, Rosa Luzia***
*University Federal of Santa Catarina, Florianópolis, Brazil
**University of Minho, Guimarães, Portugal
***University of Coimbra, Coimbra, Portugal
E-mail: liseane@civil.uminho.pt; ppereira@civil.uminho.pt; ecv1gtri@ecv.ufsc.br; jpais@civil.uminho.pt; rluzia@dec.uc.pt

Abstract

Asphalt rubber from wet process requires batching blending and reaction time associated to blending rubber and conventional asphalt to produce asphalt rubber. The ideal blending of these materials depends on the combination of very important variables, such as the amount of rubber, reaction time and temperature reaction. This paper intends to optimize the laboratory production of asphalt rubber using the continuous blend process. The rubber from waste tyres was reduced by ambient grinding and the conventional asphalt used was the 50/70 pen asphalt, currently applied in Brazil mixtures. In order to obtain the desiderable asphalt rubber, nine asphalt rubbers were produced, varying the rubber content, reaction time and temperature. The asphalt rubber properties were evaluated through current tests: (i) penetration; (ii) softening point; (iii) resilience; (iv) apparent viscosity using a Brookfield viscometer. Additionally, the microstructure of the asphalt rubbers was evaluated by scanning electron microscopy (SEM).

INTRODUCTION

In recent years, the rapid growth of the world population and industrialization levels have been resulted in increased demand of transportation. In addition, this growth generates a lot of waste products, which represents a great concern for the environment. One of the most worrying waste problems is how to deal with scrap tyres. However, waste recycling can be used to improve the performance of asphalt pavements. Many approaches have been considered for treating and improving asphalts binders through the incorporation of crumb rubber from waste tyres, which is known as asphalt rubber. Besides the ecological solution, tyre recycling is highly important at an economical level as it enhances the properties of asphalt when applied in asphalt mixtures, namely fatigue and permanent deformation performance. In addition to that, the use of asphalt rubber is highly recommendable in tropical countries, where the normal temperature in summer time makes the asphalt material become softer, reducing the service life of the road.

The use of asphalt rubber enhances the properties of the asphalt mixtures, but many variables affect the blend process, such as the amount of crumb rubber, reaction (digestion) time and temperature. As a result, in order to produce the asphalt rubber with optimized properties, a set of laboratorial tests were carried out in this study. Those tests were performed by using tyre crumb rubber from ambient grinding and the conventional 50/70 pen asphalt, currently applied in Brazilian mixtures. The optimized asphalt rubber was selected considering the results of the following tests: (i) penetration; (ii) softening point; (iii) resilience; (iv) apparent viscosity. A Scanning Electron Microscopy (SEM) was used to support the final choice.

BACKGROUND

Asphalt Rubber Definition

According to the ASTM D 8 definition, asphalt rubber is a blend of asphalt cement, crumb rubber and certain additives. The mixture contents at least 15 percent of rubber which has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles. By definition, asphalt rubber is prepared using the wet process and the specifications fall within the ranges listed in ASTM D 6114.

The wet process is a method that blends crumb rubber with the asphalt cement before the binder is incorporated into the asphalt paving materials, whereas in the dry process, the crumb rubber is used as a fine aggregate.

Asphalt rubber is used as a binder in various types of flexible pavement construction, including surface treatments and hot mixtures. Asphalt rubber reacts at high temperatures. It is agitated in tanks to favour the physical interaction of the asphalt cement and the crumb rubber constituents (Caltrans, 2003).

The performance of the asphalt rubber binder depends on its elastomeric properties which are influenced by the manufacturing process. Therefore, it is important to achieve the required digestion through adequate dispersion to create a rubber network or matrix within the asphalt. The physical aspect of mixing creates a physic-chemical interaction between the asphalt and the rubber (Oliver, 1982).

Crumb Rubber

Crumb rubber is a general term used to describe a granular rubber from waste tyres that are reduced in size to be used as a modifier in asphalt paving materials. The properties of the crumb rubber that can affect the final mixture, including the production process, are: a) particle size; b) chemical composition; c) specific surface area (Heitzman, 1992).

Crumb rubber is obtained from tyres through two principal processes: (i) ambient, which is a method of processing where scrap tyre rubber is ground or processed at or above ordinary room temperature; (ii) cryogenic, the process that uses liquid nitrogen to freeze the scrap tyre rubber until it becomes brittle. Later a hammer is used to shatter and mill the frozen rubber into smooth particles. In both processes, all the steel and nylon fluff is removed with magnets and blowers at appropriate stages of the production. The ambient process provides irregularly shaped torn particles with relatively large surface areas that promote the reaction with asphalt cement reasonably fast; while the cryogenic process produces a clean flat surface which, in turn, reduces the reaction rate with asphalt cement. However, cryogenically ground rubber also gives lower elastic recovery compared to ambient ground rubber (Roberts et al., 1989; Caltrans, 2003).

Asphalt Rubber Production

To produce acceptable asphalt rubber binder it is necessary to establish the digestion temperature and time for a specific combination of asphalt cement and crumb rubber. The viscosity of the blend is checked at different time intervals during the blending and digestion processes. The viscosity of the blend increases with digestion time and then levels. The fact of achieving a reasonably constant viscosity indicates that the initial reaction is nearly complete and that the binder is ready to be used (Kandhal, 1992).

The gradual change in the viscosity of the binder has been used to indicate the progress of the interaction between asphalt and rubber. Green and Tolonen (1977) emphasize the importance of controlling the swelling processes through controlling the interaction time and temperature and concluded that temperature has two effects on the interaction process. The first effect is related to swelling rate of rubber particles. As the temperature increases, the swelling rate increases. The second effect is on the extent of swelling. The increase in temperature makes the extent of swelling decrease. (Abdelrahman, 2006).

The time and temperature of digestion of crumb rubber with bitumen are known to have an important effect on the resulting crumb rubber binder. The major effect is related to absorption of aromatic oils in the bitumen by the rubber particles and physical changes occur: Softening and swelling of the rubber particles, so that a comparatively large proportion of the binder consists of soft rubber. At the same time, the bitumen hardens because of the loss of oils. (Oliver, 1982).

Asphalt Rubber Improvements in Asphalt Mixture

At high temperatures, the asphalt binder tends to flow easier due to the natural decrease of viscosity associated with higher temperatures. This condition creates a "softer" asphalt mixture, which is prone to rutting. The addition of crumb rubber to the HMA provides extra viscosity, thus stiffening the HMA at higher temperatures (Takallou et al., 1997; Chipps et al., 2001).

At intermediate temperatures, the asphalt mixture must be able to withstand cyclic loading as well as minimize tensile strains. The tensile strains occur at the bottom of the asphalt layer due to excessive bending and migrate upward (called reflective cracking). This ultimately compromises the structural integrity of the asphalt mixture layer. By adding crumb rubber to the asphalt mixture, an increase in resilience within the layer occurs, providing more elasticity during bending. Works conducted by Gopal et al. (2001) concluded that the addition of crumb rubber favours the energy absorption properties of the asphalt mixture, thus reducing potential failure due to cyclic loading. However, the authors also recommended that optimum rubber content should be determined for each particular crumb rubber size and asphalt binder type.

At low temperatures, the asphalt mixture must not be too stiff. It is well known that if an asphalt mixture has a high modulus at low temperatures, it will be very prone to cracking. Therefore, to help withstand cracking at low temperatures, the asphalt mixture must have a lower stiffness and a higher creep. Creep is defined as the deflection of the asphalt mixture under a constant load. Results from a number of researchers have shown that the addition of crumb rubber decreases stiffness and increases the creep properties of the asphalt mixture (Bahia and Davies, 1994; Takallou et al., 1997; Kim et al., 2001; Gopal et al., 2002).

TESTS RESULTS

Materials

The conventional asphalt used was CAP-50/70 (classified by penetration), in accordance with the specifications DNIT 095/2006 EM (Departamento Nacional de Infra-Estrutura de Transportes, Cimentos Asfálticos do Petróleo – Especificação de Material, in Portuguese). Table 1 presents the results of the CAP-50/70 characterization tests.

Table 1 – Tests results of CAP-50/70

Test	Standard	Specification	CAP 50/70
Penetration 0,1 mm (100 g, 25 °C, 5 s)	ASTM D 5	50-70	51.5
Softening point (°C)	ASTM D 36	46 min.	51.5
Resilience (%)	ASTM D5329	-	0
Apparent viscosity* 177 °C (cP), (Brookfield, *spindle 21*)	ASTM D 2196	57-285	127

The crumb rubber used was processed in ambient grinding. The rubber gradation was tested in accordance with the requirements of ASTM C136, amended by Greenbook (2000) recommendations. The results showed that the crumb rubber used followed the ADOT requirements type B (ADOT A-R Specifications, Section 1009, 2005) and are presented in Table 2.

Table 2 – Crumb rubber gradation

Sieve size (mm)	% passing	% passing (ADOT type B)	
		mín.	max.
2.00	100	100	100
1.18	99	65	100
0.60	96	20	100
0.38	14	0	45
0.075	4	0	5

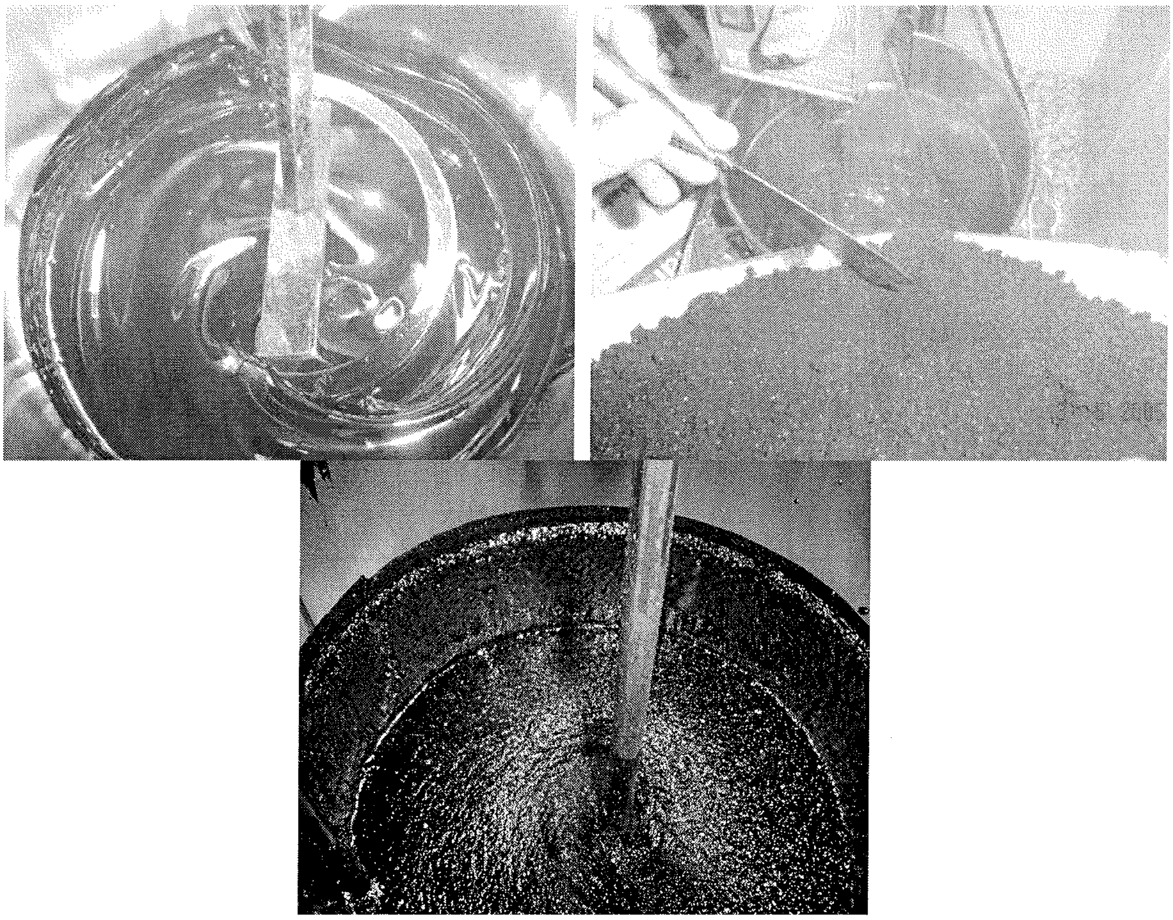
Asphalt Rubber Produced in Laboratory

In order to obtain the continuous blend asphalt rubber from conventional asphalt (CAP-50/70) and ambient crumb rubber, several percentages of rubber at different digestion time and temperatures were tested using: a) softening point; b) penetration; c) resilience and d) Brookfield viscosity.

In laboratory, the equipment used in the production of asphalt rubber was composed by an oven, equipped with temperature control and an assembly of engine and a paddle that facilitated blending of the conventional asphalt and the crumb rubber. The paddle velocity was chosen in order to produce a homogeneous mixture and its values ranged from 250 to 300 rpm. In the continuous blend process, the conventional asphalt is heated until the selected temperature (Figure 1a). Then, the crumb rubber is added (Figure 1b). Finally, the blend process starts and the asphalt rubbers swell (Figure 1c). After the time reaction, the asphalt rubber is ready to be tested.

In this study, nine asphalt rubbers were tested through the following variables:

- amount of rubber: 19, 21, 25%;
- reaction time: 45, 60, 90 minutes;
- reaction temperature: 180 °C.



(a) (b) (c)

Figure 1 – Continuous blend asphalt rubber produced at laboratory

The selection of optimized asphalt rubber was made according to the tests results. This selection was based on ASTM D 6114 (1997), which is the specification that covers asphalt rubber binders. Binder type II that specifies the asphalt rubber that will be submitted at ambient temperatures between -9 °C and 43 °C is presented in Table 3. Some transportation agencies, such as Caltrans and ADOT, have limited the apparent viscosity in 4000 cP.

Table 3 – Asphalt rubber type II (ASTM D 6114, 1997)

ASTM D 6114 specification	Asphat rubber type II
Apparent viscosity 175 °C (cP) min.	1500-5000
Penetration, 25 °C, 100 g, 5 s (0.1 mm)	25 - 75
Softening point (°C) min.	54.4
Flash point (°C) min.	232.2
Resilience (%) min.	20

The results of the tests for penetration, softening point, resilience and apparent viscosity (Brookfield viscometer) are depicted in Figures 2, 3, 4 and 5 respectively. All figures are presented considering the reaction time over amount of rubber.

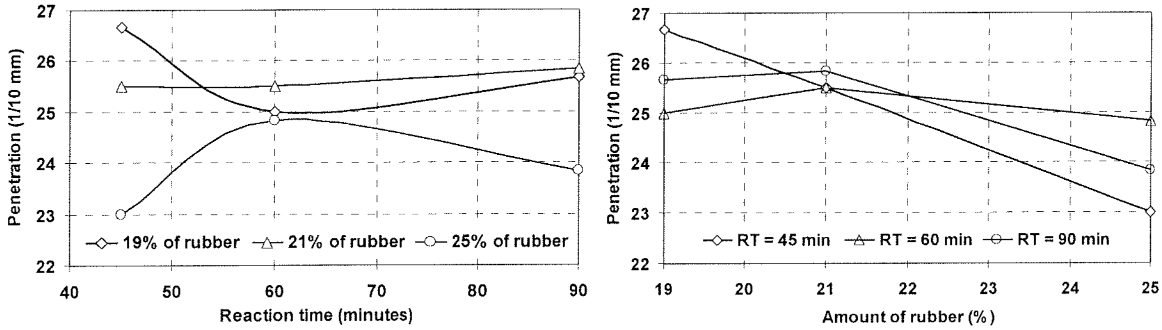


Figure 2 – Penetration tests results

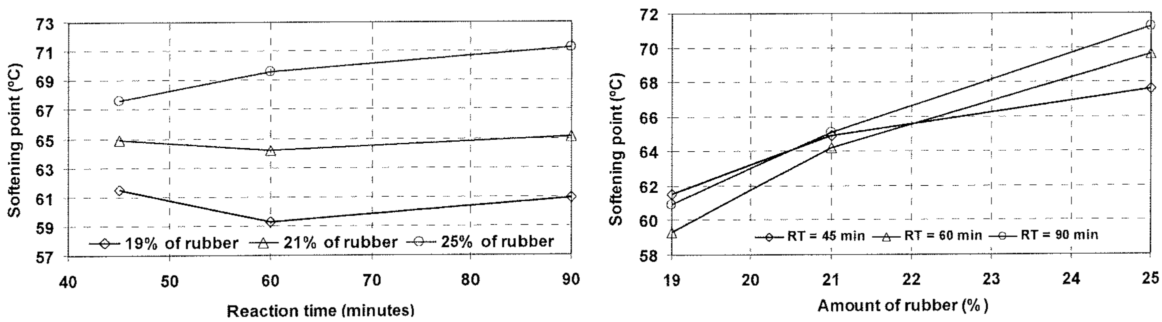


Figure 3 – Softening point tests results

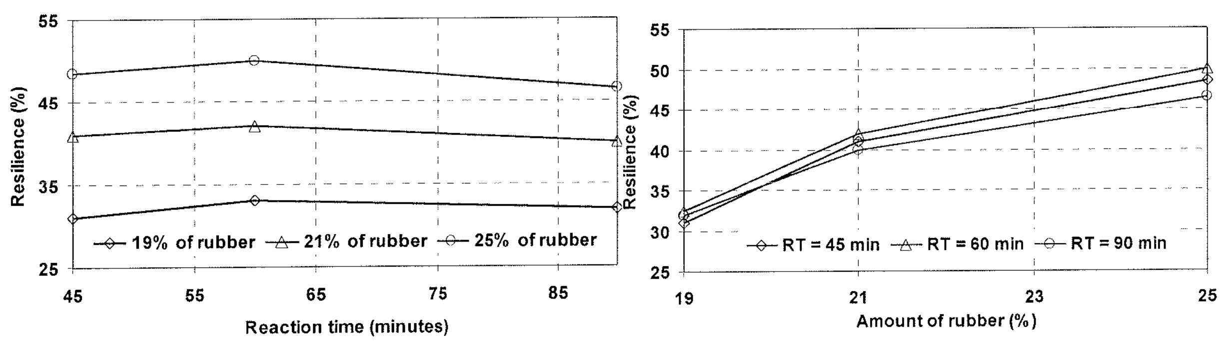


Figure 4 – Resilience tests results

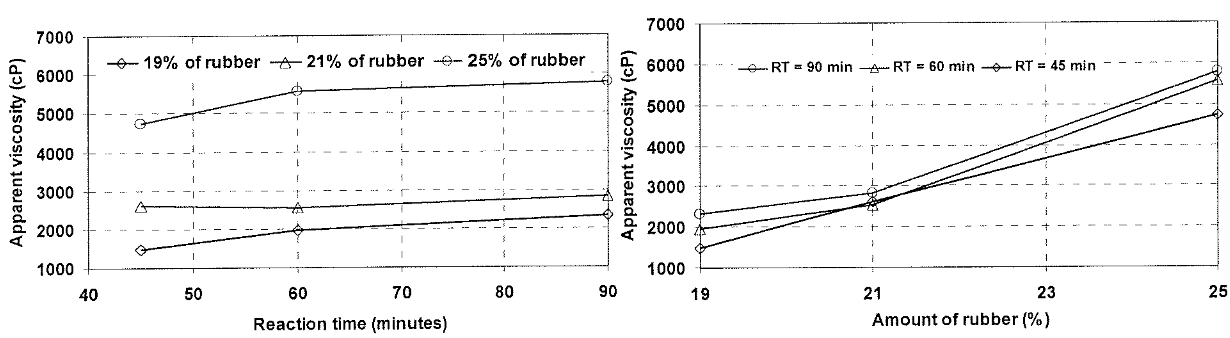


Figure 5 – Apparent viscosity tests results

From the tests results, the following can be concluded:

- Figure 1 –penetration decreases as the amount of rubber increases and for an amount of rubber up to 21% the value of the penetration remains almost constant for the three reaction times. The most significant influence was verified for the largest amount of rubber incorporated (25%). This behaviour is justified because the rubber addition makes the asphalt more viscous. The reaction time mainly influenced the value of the penetration for 25% of rubber;

- Figure 2 – the softening point increases as the amount of rubber increases. This indicates the good performance to permanent deformation. It was also observed that when the amount of rubber is close to 21%, the softening point values were similar for the three reaction times;
- Figure 3 – the resilience results were mainly influenced by the amount of crumb rubber added to the asphalt. The reaction time had not a significant effect in the change of the properties of the asphalt. On the other hand, it was verified that the addition of crumb rubber in conventional asphalts increases the elastic properties of conventional asphalt (See Table 1, resilience zero to CAP-50/70);
- Figure 4 – the amount of rubber is directly related to viscosity. The presence of crumb rubber had a significant effect in the increase of the asphalt viscosity; The effect of the reaction time was not significant, but it presents a tendency to become constant after 60 to 90 minutes.

This study allowed concluding that the amount of crumb rubber significantly influences the behaviour of the asphalt rubber. Considering that viscosity is one of the main physical properties of asphalts and that is directly related to their pumping capacity, mixture workability and application, a detailed study was carried out to verify the influence of this property in relation to reaction time.

In relation to viscosity, 14 asphalt rubbers were produced and only the apparent viscosity was measured by using the following variables: (i) amount of rubber: 23%; (ii) reaction time: 30, 60, 90, 120, 150, 180, 210 minutes; (iii) temperature reaction: 190, 200 °C. The tests results are shown in Figure 6.

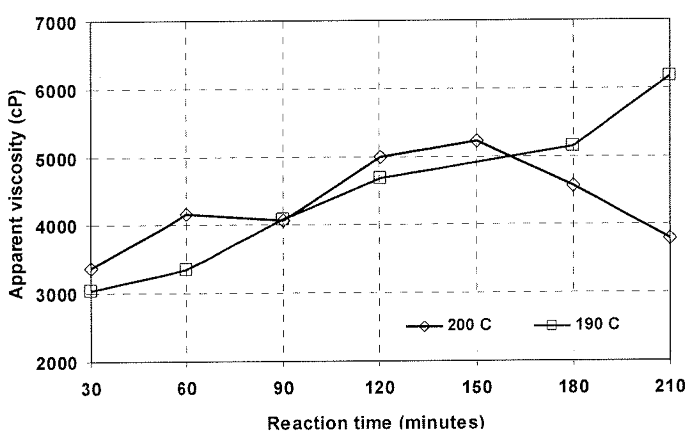


Figure 6 – Study of apparent viscosity results

A detailed study showed that viscosity at 190 °C and after 210 minutes, the reaction time still increases; at 200 °C, after 150 minutes of reaction, viscosity starts to reduce. This viscosity reduction can be explained considering that in the first phase of the asphalt rubber production process, rubber particles begin to swell, the conventional asphalt is modified at a determined time and temperature reaction. When temperature increases, the reaction required to modify the asphalt is smaller, rubber despolymerization begins and the viscosity is reduced. In the case of 190 °C, the asphalt rubber would need more than 210 minutes to begin the viscosity reduction.

The viscosity results over the reaction time for all asphalt rubbers are presented in Figure 7.

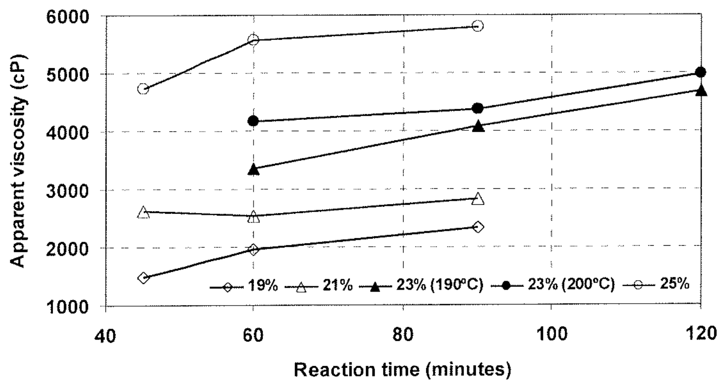


Figure 7 – Apparent viscosity results and reaction time for all blends

From the results, 19% to 23% of rubber fulfils the ASTM specifications. However, for 4000 cP, the amounts of rubber are limited to19 and 21%. The specifications of CAP-50/70 recommend that the asphalt should be heated until 180 °C. Considering two desirable reaction times (60 and 90 minutes), the microstructure of asphalt rubbers was evaluated by a Scanning Electron Microscopy (SEM) for 30, 45, 60 and 90 minutes of reaction time, at 180 °C and 21% of crumb rubber.

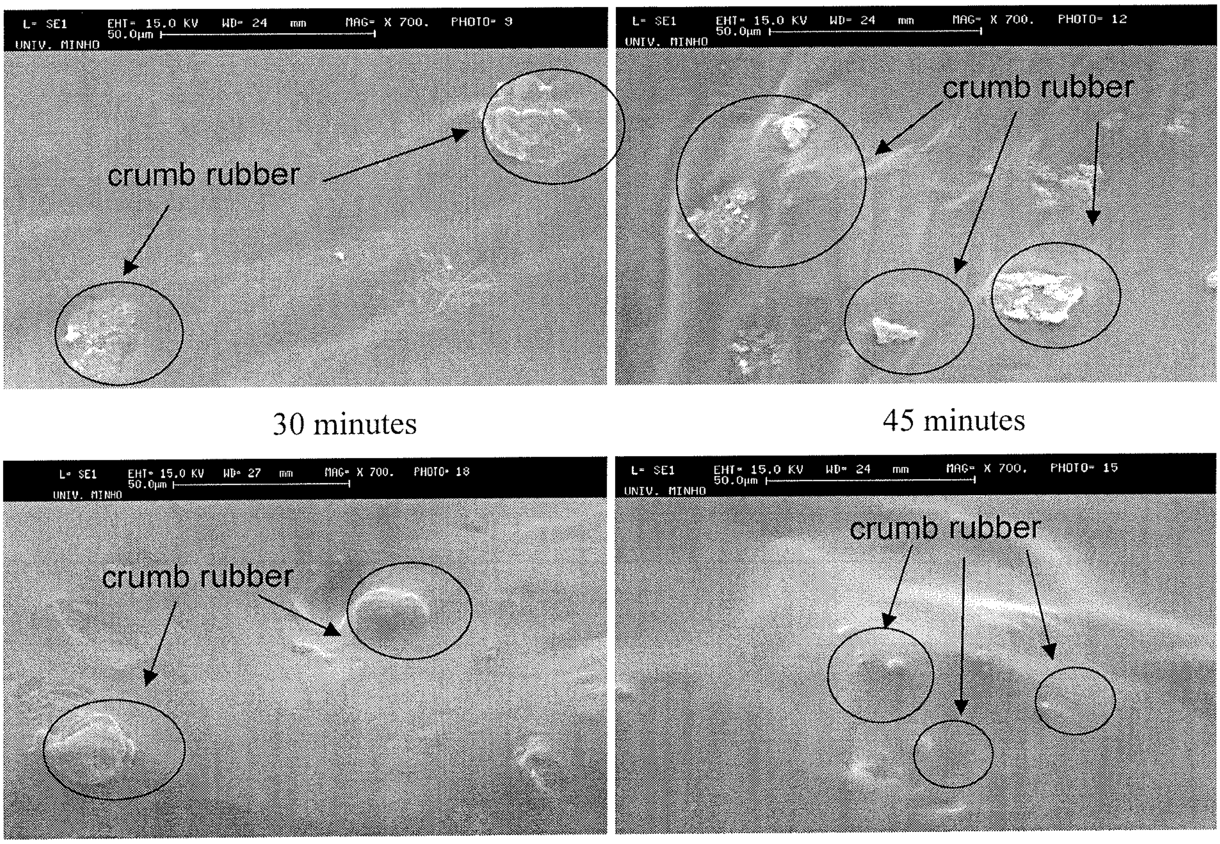
Figure 8 shows the micrographs of the finished asphalt rubber binder. Relatively large chunks of rubber are present after 30 and 45 minutes of reaction time. In 60 and 90 minutes of reaction time, the asphalt rubber structures show the compatibility system. In 90 minutes of reaction time, the crumb rubber is completely incorporated into the asphalt.

The optimized asphalt rubber to produce asphalt mixtures selected in this study resulted as:

- amount of rubber: 21%;
- reaction time: 90 minutes;
- temperature reaction: 180 °C.

CONCLUSION

This study demonstrates that the amount of rubber added to asphalt highly influences the asphalt rubber characteristics. The viscosity of the asphalt rubber is an important feature that has been evaluated in full detail. The addition of crumb rubber to a conventional asphalt showed that its properties are improved. The increase of the resilience with the incorporation of the rubber improves the elastic recovery. The use of a Scanning Electron Microscopy (SEM) is a fine tool to evaluate the asphalt rubber morphology. In order to select the optimized asphalt rubber, the properties should be measured and evaluated before its application in asphalt mixtures.



30 minutes 45 minutes

60 minutes 90 minutes

Figure 8 – Micrographs of the finished asphalt rubber binder

ACKNOWLEDGMENTS

The fourth author was supported by the Programme AlBan, the European Union Programme of High Level Scholarships for Latin America, scholarship nº E04D040507BR between 2004 and 2006. Currently, the fourth author is supported by CNPQ (Conselho Nacional de Desenvolvimento Científico e Tecnológico). The authors wish to express their gratitude to Greca Asfaltos for supplying the asphalt and the rubber.

REFERENCES

Abdeirahman, M. (2006). Controlling the performance of crumb rubber modifier (CRM) binders through the addition of polymer modifiers. *85th Annual Meeting of the Transportation Resesarch Board*, Washington, DC, USA.

Bahia, H.U.; Davies, R. (1994). Effect of crumb rubber modifiers (CRM) on performance related properties of asphalt binders. *Journal of the Association of Asphalt Paving Technologies*, Vol. 63, 1994, pp. 414 – 441.

Caltrans (2003). Maintenance technical advisory guide (TAG). Caltrans, State of California Department of Transportation, Sacramento, California, USA.

Chipps, J.F.; Davison, R.R.; Estakhri, C.K.; Glover, C.J. (2001). Field tests and economic analysis of high-cure crumb-rubber modified asphalt binders in dense-graded mixes. *80th Annual Meeting of the Transportation Research Board*, Washington, D.C., USA.

Green, E.; W. Tolonen. (1977). The chemical and physical properties of asphalt-rubber mixtures. Part I-Basic Material Behaviour. Report FHWA-AZ-HPR14-162. Arizona Department of Transportation, USA.

Greenbook (2000). Standard Specifications for Public Works Construction, 2000 Edition, Anaheim, USA.

Gopal, V.T.; Sebally, P.; Epps, J. (2002). Effect of crumb rubber particle size and content on the low temperature rheological properties of binders. *81th Annual Meeting of the Transportation Research Board*, Washington, D.C., USA.

Heitzman, M.A. (1992). State of the practice – design and construction of asphalt paving materials with crumb rubber modifier, FHWA-SA-92-022, Federal Highway Administration, Washington, D.C., USA.

Kandhal, P. S. (1992). Waste materials in hot mix asphalt – an overview. NCAT – National Center for Asphalt Technology report n.92-6. Auburn, Alabama, USA.

Kim, S.; Loh, S.; Zhai, H.; Bahia, H. (2001). Advanced characterization of crumb rubber modified asphalts using protocols developed for complex binders. *80th Annual Meeting of the Transportation Research Board*, Washington, D.C., USA.

Oliver, J.W.H. (1982). Optimizing the improvements obtained by the digestion of comminuted scrap rubber in paving asphalts. *Proceedings of. Assoc. Asphalt Paving Tech.*, Vol. 51, pp.169-188.

Roberts, F.L.; Kandhal, P.S.; Brown, E.R.; Dunning, R.L. (1989). Investigation and evaluation of ground tire rubber in hot mix asphalt. National Center for Asphalt Technology. NCAT Report 89-3, USA.

Takallou, H.B.; Bahia, H.U.; Perdomo, D.; Schwartz, R. (1997). Use of SUPERPAVE technology and construction of rubberized asphalt mixtures. *Transportation Research Record 1583*, TRB, National Research Council, Washington D.C., pp. 71 – 81.