LABORATORY OPTIMIZATION OF CONTINUOUS BLEND ASPHALT RUBBER

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Abstract

Asphalt rubber from wet process, named continuous blend required batching blending and reaction time associated with blending rubber and conventional asphalt to produce asphalt rubber. The ideal blending of these materials is dependent on the combination of the most important variables such as amount of rubber, reaction time and temperature reaction. These paper intents to optimize in laboratory the asphalt rubber produced by continuous blend process. The rubber from waste tires was reduced by ambient grinding and the conventional asphalt used was the CAP-50/70, currently applied in Brazil mixtures. In order to obtain the desire asphalt rubber, nine asphalt rubbers was produced, varying the variables (amount of rubber, reaction time, and temperature reaction). The asphalt rubbers properties were measured through the current tests: (i) penetration; (ii) softening point; (iii) resilience; (iv) apparent viscosity using a Brookfield viscometer. In addition, the microstructure of the asphalt rubbers was evaluated by scanning electron microscopy (SEM).

1. INTRODUCTION

In the recent years, the rapid growths of population and industrialization levels have been resulted in increased for demand of transportation. In addition, this growth generates a lot of waste products, which represents a great concern. One of the worrying waste problems is how to deal with scrap tires. However, the improvement of asphalt pavements and waste recycling can be to solve together. Many approaches have been considered for treating and improving asphalts binders through the incorporation of the crumb rubber from waste tires in it, called, asphalt rubber. Besides the ecological solution, tire recycling has the great economical importance and the enhancement of the properties of the asphalt when apply in asphalt mixtures such as better fatigue and permanent deformation performance have been proved. In addition the use of asphalt rubber is indicating in tropical countries, where the normal temperature in summer time will make the asphalt material become softer that reduce the service life of the road.

The use of asphalt rubber enhance the properties of the asphalt mixtures, but many variables affect the blend process, such as, amount of crumb rubber, reaction (digestion) time and temperature reaction. As a result, in order to produce the asphalt rubber with optimized properties, a set of laboratorial tests were done in this study. The tests were taken using a tire rubber from ambient grinding and the conventional asphalt CAP-50/70, currently applied in Brazil mixtures. The optimized asphalt rubber was selected in agreement with the results of the following tests: (i) penetration; (ii) softening point; (iii) resilience; (iv) apparent viscosity. Scanning electron microscopy (SEM) was used to supporting the final choose.

2. BACKGROUND

2.1. Asphalt rubber definition

According to the ASTM D 8 definition, asphalt rubber is a blend of asphalt cement, crumb rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and 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.

Wet process is a method that blends crumb rubber with the asphalt cement before incorporating the binder into the asphalt paving materials, whereas in a 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. The asphalt rubber is formulated and reacted at elevated temperatures and under high agitation to promote 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. The manufacturing process influences these properties. 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).

2.2. Crumb rubber

Crumb rubber is a general term used to describe a granular rubber from waste tires that is reduced in size for use as modifier in asphalt paving materials. The properties of the crumb rubber that can affect the interaction include production process, particle size, specific surface area, and chemical composition (Heitzman, 1992).

Crumb rubber is obtained from tires through two principal processes: (i) ambient, which is a method of processing where scrap tire rubber is ground or processed at or above ordinary room temperature; (ii) cryogenic, the process that uses liquid nitrogen to freeze the scrap tire rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles. In both process, all the steel and nylon fluff is removed with magnets and blowers at appropriate stages of the production. Ambient process provide irregularly shaped, torn particles with relatively large surface areas that promotes the reaction with asphalt cement reasonably fast; while 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 the ambient ground rubber (Roberts et al., 1989; Caltrans, 2003).

2.3. 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. Viscosity of the blend is checked at different time intervals during the blending and digestion process. Viscosity of the blend increases with digestion time and then levels off. Achieving a reasonably constant viscosity indicates that the initial reaction is nearly complete and the binder are ready to use (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 & 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 on the rate of swelling of rubber particles. As the temperature increases, the rate of swelling increases. The second effect is on the extent of swelling. As the temperature increases, the extent of swelling decreases (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 probably absorption by the rubber particles of aromatic oils in the bitumen. This causes 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 phase hardens because of loss of oils. These are all physical changes (Oliver 1982).

2.4. 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 an increased viscosity contribution, 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 so 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. Work conducted by Gopal et al. (2001) concluded that the addition of crumb rubber aids in the energy absorption properties of the asphalt mixture, therefore reducing the potential for 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 temperature, 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 both decreases the stiffness and increases the creep properties of the asphalt mixture (Bahia & Davies, 1994; Takallou et al., 1997; Kim et al., 2001; Gopal et al., 2002).

3. TESTS RESULTS

3.1. Materials

The conventional asphalt used was CAP-50/70 (classified by penetration), in agreement 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 ºC, 5 s)	ASTM D 5	50-70	51,5
Softening point (ºC)	ASTM D 36	46 min.	51,5
Resilience (%)	ASTM D5329	-	0
Aparent viscosity* 177 ºC (cP), (Brookfield, *spindle 21*)	ASTM D 2196	57-285	127

The crumb rubber used was processed in ambient grinding. The rubber gradation were tested in accordance with the requirements of ASTM C136, amended the Greenbook (2000) recommendations. The results shown that 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

3.2. Asphalt rubber produced at laboratory

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

In laboratory, the equipment used in the production of asphalt rubber is composing by an oven, equipped with temperature control and an assembly of engine and paddle that facilitates 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 continuous blend process, the conventional asphalt is heated until the temperature chooses (Figure 1a). Then, the crumb rubber is added (Figure 1b). Finally, the blend process starts and the asphalt rubbers swelling (Figure 1c). After last the time reaction, the asphalt rubber is ready to be tested.

(a) (b) (c)

Figure 1 – Continuous blend asphalt rubber produced at laboratory

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

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

The selection of optimized asphalt rubber was done according the tests results. This selection was based in ASTM D 6114 (1997), which is the specification that covers asphalt rubber binders. The binder type II that specifies the asphalt rubber that will be submitted at ambient temperatures between -9 ºC and 43 ºC, is presents in Table 3. Some transportation agencies, 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 ºC (cP) min.	1500-5000
Penetration, 25 ºC, 100 g, 5 s (0,1 mm)	25 a 75
Softening point (ºC) min.	54,4
Flash point (ºC) min.	232,2
Resiliência (%) min.	20

The tests penetration, softening point, resilience and apparent viscosity (Brookfield viscometer) tests results are presents in Figures 2, 3, 4 and 45 respectively. All figures are presented over the reaction time and over amount of rubber.

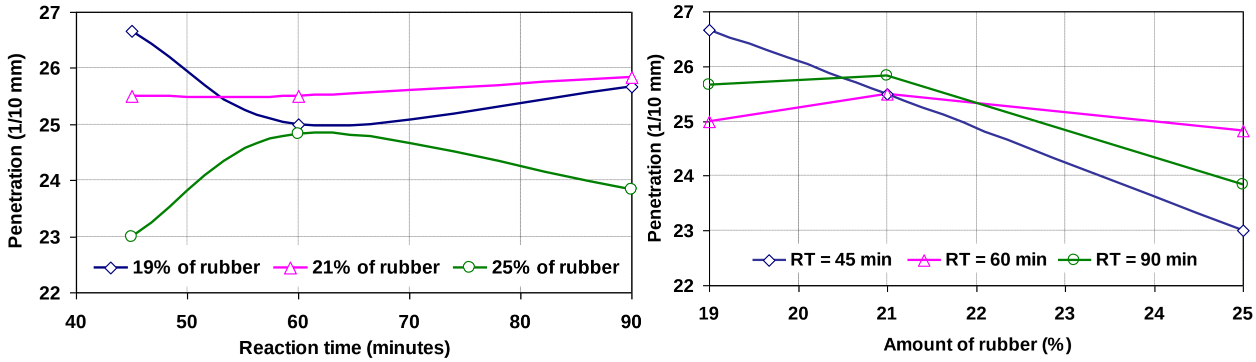

Figure 2 – Penetration tests results

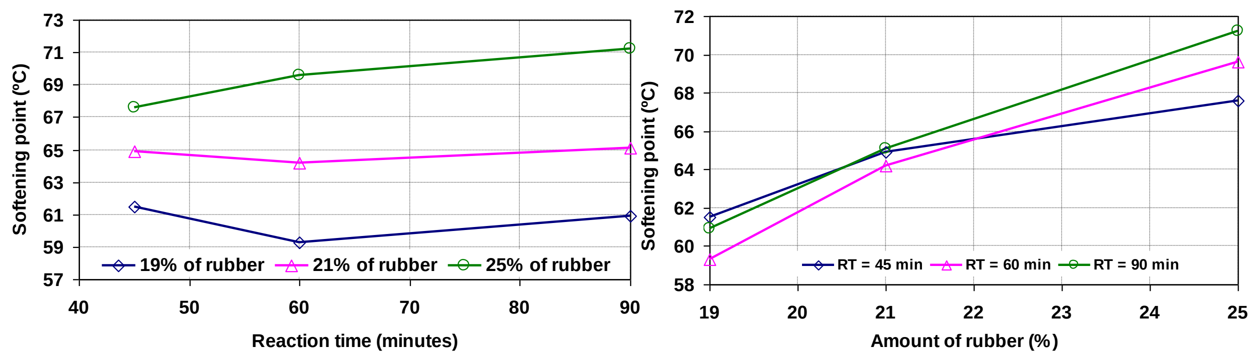

Figure 3 – Softening point tests results

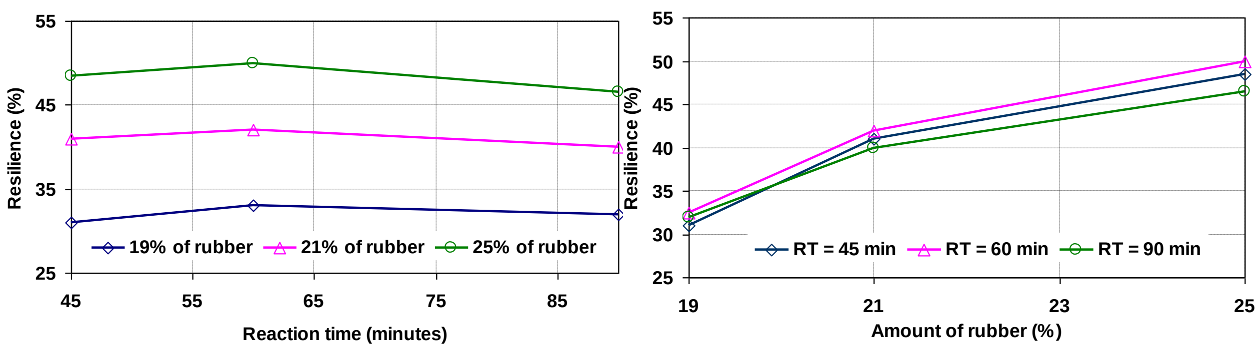

Figure 4 – Resilience tests results

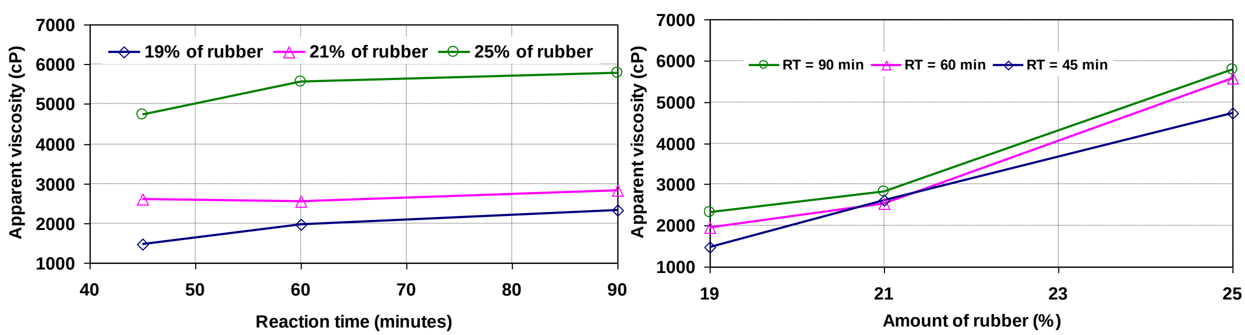

Figure 5 – Apparent viscosity tests results

From the tests results, the following can be concluding:

- Figure 1 – the penetration decreased as the amount of rubber increases and for amount of rubber up to 21% the value of the penetration stays almost constant for the three reaction times. The most significant influence was verified for the largest amount of rubber incorporates (25%). This behavior is justified because the rubber addition turns the asphalt more viscous. The reaction time influenced mainly the value of the penetration for 25% of rubber;
- Figure 2 – the softening point increases as the amount of rubber increases, which can be an indicative the good performance to permanent deformation. Also was observed that at 21% of crumb rubber, the softening point values were similar for the three reaction times;
- Figure 3 – the resilience results were influenced mainly by the amount of crumb rubber added to the asphalt. The reaction time has not a significant effect in the change of the properties of the asphalt. On the other hand, was verified that the addition of the crumb rubber in the conventional asphalt increases the elastic properties of the conventional asphalt (See Table 1, resilience zero to CAP-50/70);
- Figure 4 – the amount of rubber influences in a major way the viscosity. The presence of the crumb rubber had a significant effect in the increase of the viscosity of the asphalt and, depending on the amount of rubber; the viscosity values allowed by the specification (ASTM D 6114, 1997) were exceeding (as 25% of crumb rubber). The effect of the reaction time was not significant, but it presents a tendency to become constant between the 60 and 90 minutes.

The study accomplished until here, allowed concluding that the amount of crumb rubber influences significantly the behavior of the asphalt rubber. Considering that the viscosity is one of the main physical properties of the asphalts and this relation with pumping capacity, mixture workability and application, a detailed study was carried out to verify the influence of this property in relation to the reaction time.

For the viscosity study, more 14 asphalt rubbers were produced and only the apparent viscosity was performed, 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 ºC. The tests results are shown in Figure 6.

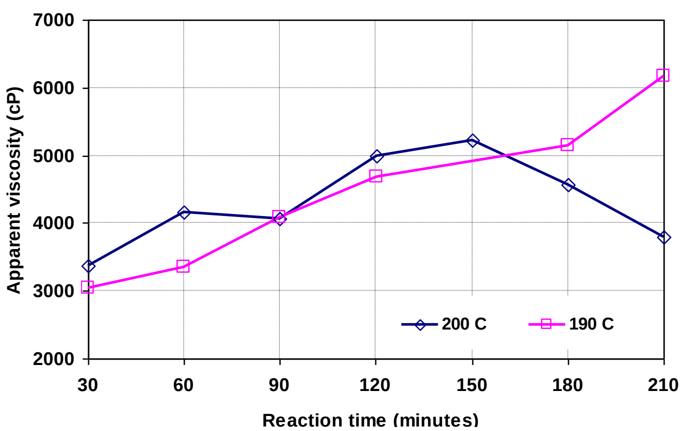

Figure 6 – Study of apparent viscosity results

The detailed study showed that the viscosity for 190 ºC at 210 minutes reaction time still increase and for 200 ºC, after 150 minutes of the reaction, the viscosity begins to reduce. This viscosity reduction can be explained because in a first phase of the asphalt rubber production process, the rubber particles begin to swelling, the conventional asphalt modifies at determined time and temperature reaction. As the temperature increase, the required reaction to promote the modification become to smaller, the rubber despolymerization begins and the viscosity is reduced. In the case of 190 ºC the asphalt rubber would need more than 210 minutes to begin the viscosity reduction.

The viscosity results over the reaction time for all asphalt rubber are presents in Figure 7.

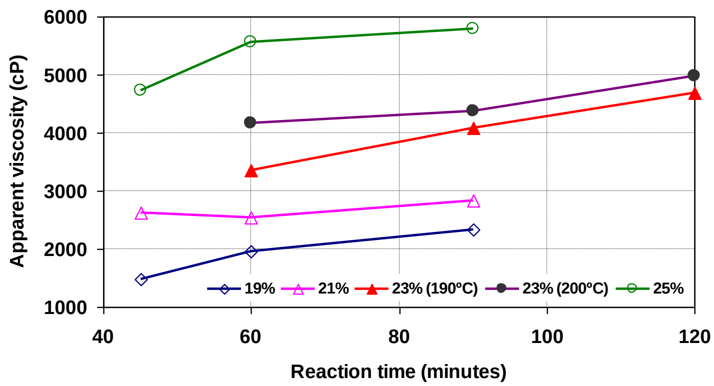

Figure 7 – Apparent viscosity results and reaction time for all blends

From the results, 19% to 23% of rubber assists 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 heat until 180 ºC. Considering two desirable times reaction (60 and 90 minutes), the microstructure of the asphalt rubbers was evaluated by scanning electron microscopy (SEM) for 30, 45, 60 and 90 minutes of reaction time, at 180 ºC and 21% of crumb rubber.

Figure 8 shows the micrographs of the finished asphalt rubber binder. It can be seen that relatively large chunks of rubber are present in 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 in 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 ºC.

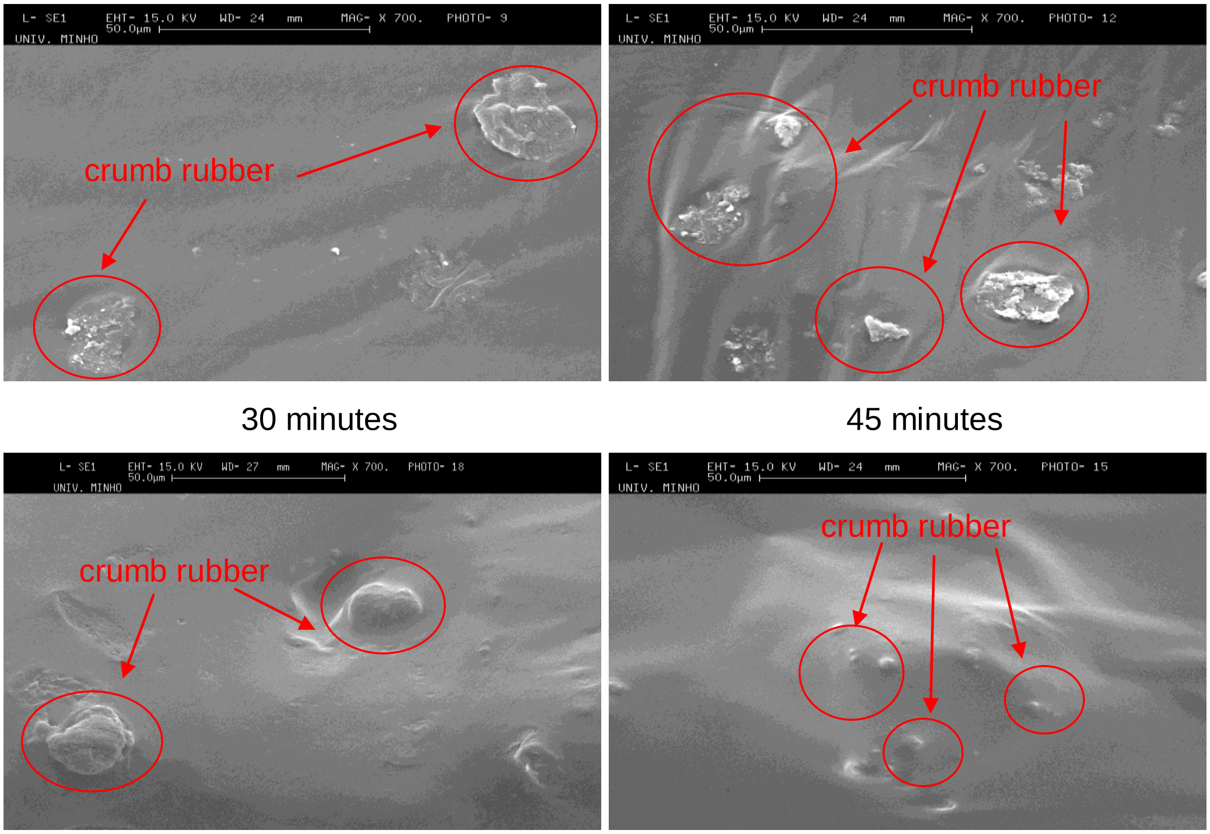

Figure 8 – Micrographs of the finished asphalt rubber binder

4. CONCLUSIONS

The study presented demonstrates that the amount of rubber influenced mainly asphalt rubber characteristics. The viscosity of the asphalt rubber is an important characteristic that has been evaluated in full detail. The addition of crumb rubber in a conventional asphalt showed that the properties are improved. The increase of the resilience with the incorporation of the rubber improves the elastic recovery. The use of scanning electron microscopy (SEM) is a good tool to evaluate the asphalt rubber morphology. In order to select the optimized asphalt rubber, the properties should be measured and evaluated before the application in asphalt mixtures.

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