Revista Ingeniería de Construcción RIC
Vol 33 Nº1 2018 www.ricuc.cl

ENGLISH VERSION

Trece años de continuo desarrollo con mezclas asfálticas modificadas con Grano de Caucho Reciclado en Bogotá: Logrando sostenibilidad en pavimentos

Thirteen Years of Continuous Development in Crumb Rubber Modified Asphalt Mixtures in Bogota: Achieving Pavement Sustainability

G. Martinez[1]*, B. Caicedo**, D. González***, L. Celis***, L. Fuentes*, V. Torres***

*Universidad del Norte, Barranquilla. COLOMBIA
**Universidad de los Andes, Bogotá. COLOMBIA
***Instituto de Desarrollo Urbano de Bogotá, Bogotá, COLOMBIA

Fecha de Recepción: 26/07/2017
Fecha de Aceptación: 20/02/2018
PAG 41-50

Abstract

The present work describes different stages that the Urban Development Institute (IDU) has addressed to achieve the adequate and correct application of crumb rubber modified (CRM) asphalt mixtures. The first research stage in the laboratory included an exhaustive analysis of the mechanical properties of the mixtures, according to asphalt mixture typologies used in Colombia. In addition to a brief application on a fatigue carousel to evaluate the deterioration of this type of mixtures under accelerated loading. The second stage deals with the performance analysis and comparison with other types of asphalt mixtures modified with polymers available in the Colombian market. This stage involved the construction of one full-scale pavement test lane with different sections considering asphalt modified with polymers (SBS, SBR), and two sections with rubber asphalt, one through dry process and the other through wet process. As a result of these stages, a technical specification was developed to serve as guidelines for the production and analysis of mixtures added with crumb rubber. Likewise, the environmental advantages of applying this technology in the Colombian context are described.

Keywords: *Asphalt mixtures, crum rubber, paviment sustainability*

Resumen

El presente trabajo describe cada una de las diferentes etapas que ha abordado el IDU para una adecuada y acertada aplicación de las mezclas mejoradas con GCR. Una primera etapa de investigación en laboratorio que incluyó una exhaustiva evaluación de las propiedades mecánicas de las mezclas de acuerdo con la tipología de las mezclas asfálticas utilizadas en Colombia. Además de una breve aplicación en un carrusel de fatiga para evaluar el deterioro de este tipo de mezclas de una manera acelerada. Una segunda etapa de evaluación y comparación del desempeño con otros tipos de mezclas asfálticas modificadas con polímeros disponibles en el mercado colombiano. Esta etapa involucró la construcción de un tramo de prueba escala real con diferentes secciones considerando asfalto modificado con polímeros (SBS, SBR) y dos secciones con asfalto caucho, una por vía seca y otra por vía húmeda. Como resultado de estas fases una especificación técnica fue desarrollada para dar lineamientos sobre la producción y evaluación de las mezclas con GCR. Se describen de la misma manera las ventajas ambientales de la aplicación de esta tecnología dentro del entorno Colombiano.

Palabras clave: Mezclas asfalticas, grano de caucho, sostenibilidad en pavimentos

1. Introduction

The disposal of discarded tires has been a serious problems both for public agencies and companies managing solid waste disposal sites. This issue, in addition to current requirements and needs established by the Kyoto protocol, motivate the constant search for environment-friendly solutions to achieve a sustainable transport infrastructure. In Bogota, the Urban Development Institute (IDU, in Spanish) has not remained indifferent to these needs and the problematic of this kind of solid waste.

Therefore, for more than a decade (2001), the IDU has made considerable efforts to study and implement crumb rubber modified (CRM) asphalt mixtures, thereby identifying its limitations and potential advantages when applied in the road network of the city of Bogota, in Colombia.

The development of an asphalt technology modified with tire waste was originated by a study carried out by the Capital District on the environmental aspect of solid waste, where the handling of used tires generated by the vehicle fleet of Santa Fe de Bogota was highlighted. One of the study's conclusion recommended a sustainable option that consists in incorporating crumb rubber (CR) from recycled tires to asphalt mixtures. This option would allow incorporating a solid waste that is difficult to dispose of, to an element of road infrastructure such as pavement, and at the same time, it would allow improving the performance and mechanical properties of the mixture.

Based on this recommendation, and as part of the Urban Transport Project for Santa Fe de Bogota (BIRF 4021-CO), the Urban Development Institute hired the Universidad de Los Andes to undertake different studies, with the aim of developing a mix design methodology, a modification methodology of national asphalts, and finally, obtaining asphalt mixtures improved with tire waste (Universidad de Los Andes 2002), (Universidad de Los Andes 2005). The present paper describes each of the different stages addressed

---

[1] *Corresponding author:*

Universidad del Norte, Barranquilla. Colombia
E-mail: arguelles@uninorte.edu.co

by the UDI for an adequate and correct application of the mixtures improved with CR. The first research stage in the laboratory included an exhaustive analysis of the mechanical properties of the mixtures, according to the typology of asphalt mixtures used in Colombia. In addition to a brief application on a fatigue carousel to evaluate the deterioration of this type of mixtures under accelerated loading. The second stage deals with the performance analysis and comparison with other types of asphalt mixtures modified with polymers available in the Colombian market.

This stage involved the construction of one full-scale pavement test lane with different sections considering asphalt modified with polymers (SBS, SBR), and two sections with rubber asphalt, one through dry process and the other through wet process. As a result of these stages, a technical specification was developed to serve as guidelines for the production and analysis of crumb rubber modified mixtures. To date, the IDU has been operative in more than 90 road sections using an important volume of discarded tires, thus contributing to the sustainability of the pavement network of Bogota. Likewise, the environmental advantages of applying this technology in the Colombian context are described.

1.1 Objective

To describe the development and progress of the process of implementation of the crumb rubber modified asphalt technique in Colombia, particularly in Bogota.

2. The Implementation Stage of Crumb Rubber Modified Asphalt in Colombia

2.1 Initial Phase: Initial experimentation in wet processes and dry processes in the laboratory and the fatigue carousel

In this stage initiated in 2001, the feasibility of incorporating CR through dry processes and wet processes was studied. The dry process consists in including CR in asphalt mixtures as if it was part of the aggregates (generally, fine particles). The mixing process of asphalt and aggregates is done in the traditional way. The CR incorporation of a specific grading is made by replacing the same sizes in the aggregates, in the desired percentages. On the other hand, the wet process implies the modification of the asphalt cement prior to the mixing with aggregates. The CRM manufacture through the dry process used asphalt cement of the Barrancabermeja refinery, the most important in Colombia; while in the wet process, asphalt cement of the refineries of Barrancabermeja and Apiay were modified. It should be highlighted that these two refineries are the only ones in Colombia that produce asphalt.

Due to the fact that at the time of the study (year 2001) there were no tire grinders available in Colombia, the crumb rubber was obtained from waste coming from truck tire retreading plants, which generated a waste in the form of gravel free from steel and nylon. The selected CR had fine particle size, with particles smaller than sieve No. 30 (595 µm), because fine particles allow a better interaction between rubber and asphalt cement. Table 1 shows the CR grading used.

Table 1. *Rubber grading proposed for the dry process*

Normal (µm)	*595*	*297*	*74*
Alternate	*No. 30*	*No. 50*	*No. 200*
Passing%	*100*	*7.5*	*1.5*

For the modification of asphalt cement with CR, different CR percentages were analyzed for both asphalt cements manufactured in Colombia. For the purpose of the present paper, the asphalt cement produced in the Apiay refinery will be designated with letter (A) and the asphalt of Barrancabermeja, with letter (B). Table 2 shows the physical properties of asphalts. Asphalt A was produced with penetration grade 60/70 dmm, and asphalt B, wioth penetration grade 70/90 dmm.

Table 2. *Physical properties of studied asphalt cements*

Code	Ductility	Elastic Recover	Penetration	Softening point	Density	Mass loss
	[25°C]	[25°C, 50 mm/min, 20 cm]	[25°C, 100 g, 5 s]		[25°C]	
	ASTM D113	ASTM T-301-95	ASTM D5	ASTM D 36	ASTM D70	ASTM D2872
	[cm]	[%]	[1/10 mm]	[°C]	[g/cm^3]	[%]
Original Asphalt Cement						
A	> 100	6.25	65	51	1.02	-
B	> 100	5	71	44.8	1.02	-
RTFO Residue						
A	48.5	-	45	51.7	0.97	1.14
B	> 100	-	54	48.8	1.03	1
RTFO+PAV Residue						
A	9.9	-	38	62.3	0.89	-
B	7.75	-	18	66.9	0.99	-

2.1.1 CR Proportion

The type of binder, the CR percentage, the mixing temperature and the reaction time were considered as input variables for the proportioning. The response variable to obtain the optimal CR amount was the Brookfield viscosity at 163°C of the binder modified with CR, which according to (Caltrans 2003) should range between 1500 and 3000 cP (10-2 Poises). The factorial design for the CR proportioning was carried out according to the indications in Table 3.

The asphalt cement was blended with the CR in a metal tank, which was introduced in a hot oil bath to heat the mixture at the specified temperature; this blend is constantly stirred by a system of metal blades at a speed of 100 rpm. As these two materials blended, samples were taken depending on the desired mixing time. This blending system guaranteed the homogeneity of the asphalt-rubber blend. The blend fulfilling the defined criteria was chosen. Among the selection criteria, the Brookfield viscosity at 163°C, lower reaction times and low mixing temperatures were considered.

Table 3. *Factorial design for the proportioning of asphalt cements*

Asphalt Cement	CR Content (%)	Blending Temperature (ºC)	Reaction Time (min)
Barranca 70/90 - (B)	15, 20	155, 165	45, 50, 55, 60, 70, 80
Apiay 60/70 - (A)	10, 13, 15, 20	155, 165	45, 50, 55, 60, 70, 80

The designation of modified asphalts was defined by the combination of the variables involved. For example, the asphalt designated A-13-165-55 was an asphalt of the Apiay refinery, 13% RC, modified at 165°C during 55 min. The asphalt cement of Apiay required the analysis of two additional CR contents in order to comply with the viscosity criterion, as shown in Figure 1.

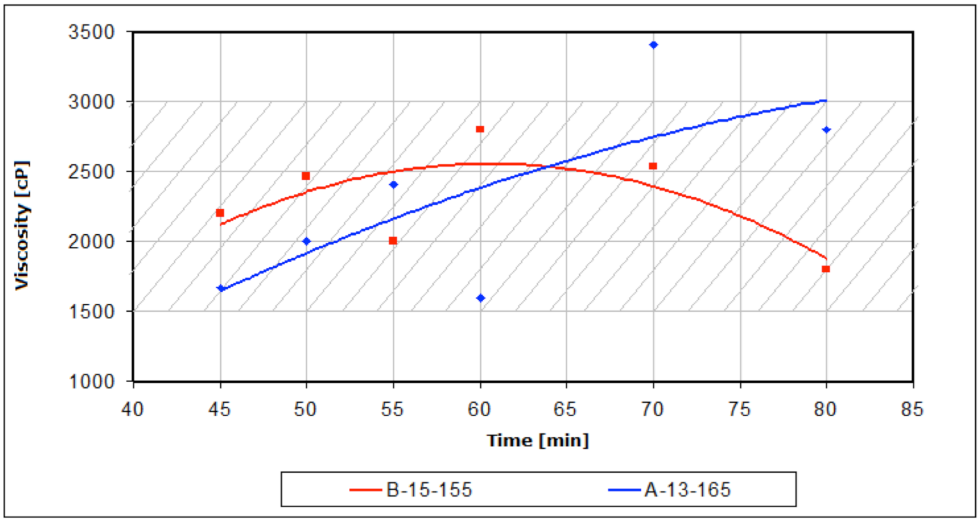

Figure 1. *Variation of the Brookfield viscosity at 163°C in relation to the mixing time, for designs A-13-165 and B-15-155*

*Finally, the combinations A-13-165-55 and B-15-155-50 were selected as the optimal proportioning, according to the previously established criteria. Based on these proportioning, a full SuperPave characterization was carried out, with the aim of determining the improvements in the performance grading (PG) of each asphalt. Thus, regarding binder A in its pure state, its performance grade was determined at PG58-2, and when modified with 13% RC, it improved to PG88-16. Likewise, in relation to binder B in its pure state, it shows a performance grade of PG58-22, which improved to PG76-22 with 15% RC. Further details on the rheology analysis of asphalts modified with tires can be found in (Martínez et al., 2006). The performance results for the Colombian CRM asphalts are shown in Figure 2. G*senδ is considered an indicator of the fatigue behavior; lower values would indicate a better performance against this type of deterioration. As shown in Figure 2, CRM asphalts, regardless of the origin of asphalts, presented a better indicator than asphalts modified with polymers.*

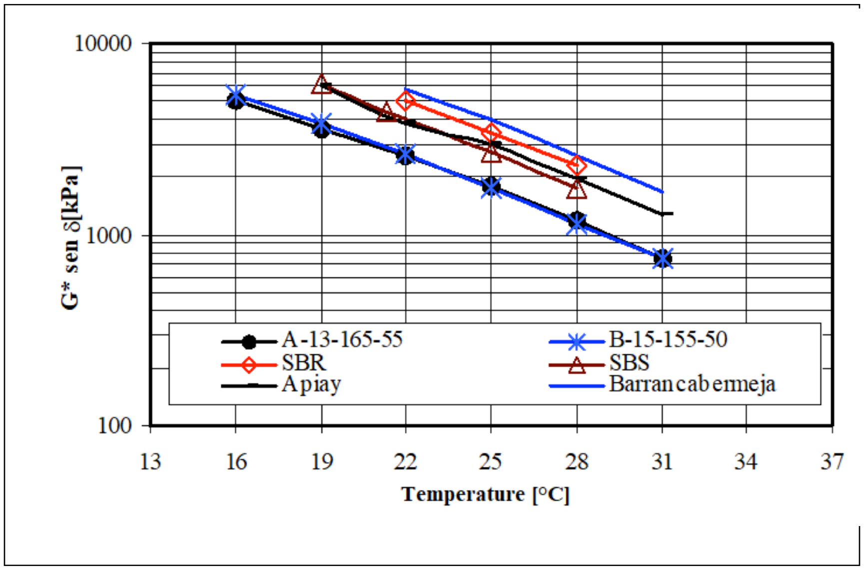

Figure 2. *Fatigue factor for Colombian CRM asphalts vs. other ones modified with polymers*

The second part of this study analyzed the effect of a CR percentage of 1 and 2% (weight % in relation to aggregates), by applying the wet process in hot dense-graded mixes of type 1 (MDC1) and type 2 (MDC-2); see Table 4.

Table 4. *Grading distribution of mixes MDC 1 and 2*

Sieve		***Passing Percentage***	
Normal	*Alternate*	*MDC-1*	*MDC-2*
25.0 mm	*1″*	*100*	*-*
19.0 mm	*3/4″*	*80-100*	*100*
12.5 mm	*1/2″*	*67-85*	*80-100*
9.5 mm	*3/8″*	*60-77*	*70-88*
4.75 mm	*No. 4*	*43-54*	*51-68*
2.00 mm	*No. 10*	*29-45*	*38-52*
425 mm	*No. 40*	*14-25*	*17-28*
180 mm	*No. 80*	*8 - 17*	*8 -17*
74 mm	*No. 200*	*4 - 8*	*4 – 8*

This stage considered the mix design and their mechanical characterization. The following tests were included:

- *Marshall Mix Design, with the aim of determining the optimal proportion of asphalt cement, and analyzing the stability, the flow and the percentage of voids in the asphalt cement, in asphalt mix designs prepared through the dry process.*
- *Compacting in the rotary compacting press to determine, through the dynamic modulus analysis and void percentage, the optimal proportion of asphalt cement in asphalt mix designs prepared through the wet process.*
- *Determination of the fatigue behavior.*
- *Determination of the Dynamic Modulus at 5, 25 and 40°C, and frequencies of 1, 4, 10 and 16 Hz.*
- *Determination of the resistance to plastic deformation through the laboratory testing lane.*
- *Table 5 shows the results of the mix design.*

The results obtained in the design show that the CR inclusion by the wet process involves higher asphalt content; consequently, lower stabilities and lower flows for the CRM mixes are observed.

This can be explained in the specific surface of CR and its asphalt absorption capacity. The dynamic modulus (this test was done according to the standard INV E-54) at 10 Hz on these mixes showed that the CR inclusion resulted in mixes with less stiffness for MDC-1 at 25°C, dynamic modulus at 0% of 58000 kg/cm2, while for mixes with 1 and 2% with CR, dynamic modulus of 25000 and 11600 kg/cm2 were obtained, respectively. For mixes of MDC-2 type, the values at 0% were 81500 kg/cm2, while for the mixes with 1 and 2% with CR, dynamic modulus of 28000 and 19200 kg/cm2 were obtained, respectively.

As evidenced, the effect of CR inclusion in the MDC is to produce a mixture that is less stiff than the conventional one, which differs from the objective of modifying asphalts (wet method) that allow obtaining higher viscosities and generating mixtures with equally higher modulus. Additionally, other tests such as permanent deformation and fatigue strength were conducted, but due to length constraints, they are not addressed in this paper. However, the results of the full-scale test with the designed mixtures show the actual performance and improvements of the CR addition through the dry process.

Table 5. *Mix design with CR through dry process of MDC mixes 1 and 2*

Test	***Voids whit air in the asphalt mix***	***Optimal percentage of asphalt cement***	***Stability***	***Flow***	***Unit Waight***	***Voids in mineral gravel***
	[%]	*[%]*	*[kg]*	*[mm]*	*[g/cm^3]*	*[%]*
Standar	*INV* E-736*	*-*	*INV E-748*	*INV E-748*	*INV E-733*	*-*
Specification	*4 - 6*		*min. 750*	*2-3.5*	*-*	*mín. 14*
MDC-1 0%	*5*	*4.7*	*1796*	*2.5*	*2.18*	*21.1*
MDC-1 1%	*5*	*5.7*	*898*	*3.1*	*2.07*	*26.5*
MDC-1 2%	*5*	*5.8*	*1012*	*3.6*	*2.09*	*26.8*
Specification	*4 - 6*		*mín. 750*	*2-3.5*	*-*	*mín. 15*
MDC-2 0%	*5*	*5.4*	*1538*	*2.6*	*2.18*	*21.6*
MDC-2 1%	*5*	*6.5*	*1429*	*3*	*2.13*	*25.1*
MDC-2 2%	*5*	*6.6*	*1077*	*3*	*2.1*	*26.8*

**INV: corresponds to the specifications of the National Roads Institute – INVIAS*

Figure 3 shows the direct full-scale application of the mix designs obtained through the modification with CR by the dry process. The fatigue carousel was built by applying a MDC-2 type of mix with 1% CR and 0% CR as control sample, because this percentage allowed obtaining the best performance of the analyzed mixes. The testing lane consisted in 7 MDC-2, which is one of the most typical mix typologies in Colombia, placed under the same support conditions, which were subjected to approximately 210,000 load repetitions of 8.2 tons.

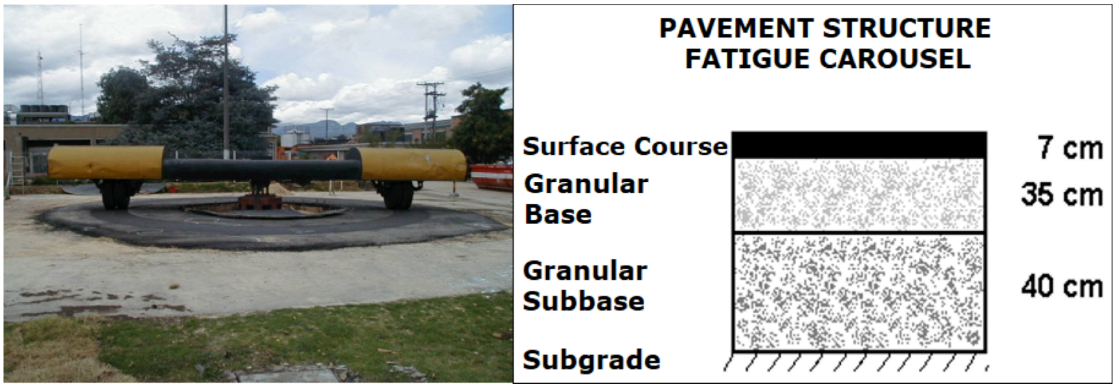

Figure 3. Full-scale test in the fatigue carousel, Universidad de Los Andes (Universidad de Los Andes 2002)

Table 6 shows the best performance of the CRM mix at 1%; the rutting for the conventional mix was 5 times higher and the cracking density as fatigue indicator showed differences around 8 times higher in relation to the modified section. The laboratory results, together with the results of the fatigue carousel, encouraged the IDU to carry out a second stage emphasizing the mix design by the wet process and the full-scale construction of a test pavement section in an urban road in the city of Bogota.

Table 6. Performance of the fatigue carousel after 210,000 load repetitions of 8.2 tons

Design	**MDC-2 0%GCR**	**MDC-2 + 1% GCR**
Test	Maximum Values	
Rutting, mm	49.28	9.96
Deflection, 10^{-2} mm	254.1	160.8
Cracking Density, cm/m^2	931	127
Recorded Temperature, °C	48	45

2.2. Test Pavement Section in Urban Road

Coherently with the results obtained in the first stage of the mix development, the second stage of the study of mechanical improvements of mixes modified with tire waste started towards the year 2003 and ended in 2015 with the final follow-up stage on the full-scale pavement section.

Due to the implementation of a new specification in Bogota, the 0/14 mix designation was used in this stage, whose grading is shown in Table 7.

Table 7. *Mix Grading 0/14*

Size	***Mix 0/14***
mm	*Passing (%)*
14	*94 – 100*
10	*72 – 84*
6,3	*50 – 66*
4	*40 – 54*
2	*28 – 40*
0,08	*7 – 10*

The blends were designed with 18% CR content in relation to the asphalt's weight, a percentage that fulfills the viscosity criteria defined in (Caltrans, 2003). For the Ecopetrol study (Colombian Oil Company), the asphalt production in Barrancabermeja was modified, and it went from producing asphalt cement penetration grade 70/90 to penetration grade 80/100. This modification forced the study to include asphalt mixes with penetration grade 80-100. Table 8 shows the mix design of the analyzed asphalts. In the table, AM indicates the conventional asphalt mix, VH indicates the CRM asphalt by wet process, VS indicates CRM asphalt by dry process, PMSBR and SBS indicate commercial asphalts modified with polymers. Further details on mix performances can be found in (Universidad de Los Andes, 2002), (Universidad de Los Andes, 2005).

Table 8. *Results of the asphalt mix designs*

Type of Mix	***Specific Gravity Bulk***	***Dinamic Modulus (Kg/cm2) 15ºC , 10 Hz***	***Voids (%)***	***Asphalt Content (%)***
AM7090	*2.124*	*140800*	*7.55*	*6.32*
VH 7090	*2.144*	*123000*	*7.2*	*6.46*
AM80100	*2.13*	*168779*	*6.54*	*6.89*
VH80100	*2.13*	*130000*	*6.5*	*6.78*
VS80100	*2.088*	*74000*	*6*	*6.78*
VH6070	*2.15*	*144849*	*6.25*	*6.89*
PMSBS	*2.155*	*130850*	*6.4*	*6.35*
PMSBR	*2.135*	*120000*	*6.5*	*6.72*

2.2.1 Construction of the Full-scale Testing Lane

The full-scale production had to meet three important conditions. The first was the problem of maintaining the temperature controlled at 163°C, the stirring energy was set at 1800 rpm, and the production was made in batches of 0.21m3. The modification process was carried out at 163°C, 25 minutes of blending time and 18% in weight of the total asphalt cement; under these conditions, a Brookfield viscosity within the range of 2000 to 2500 cP was obtained.

The test section was chosen considering the same traffic volume throughout the sections and homogenous support conditions. The length of the test section was 270 m (54 m for each type of mix), on which a complete characterization was made regarding the existing granular bases and subgrades. The lane was divided into 5 sections with the same pavement structure in granular bases and the same asphalt layer thickness, and different asphalt cement for each section. The test section is composed of one section with conventional asphalt mix, two sections with CRM asphalts through dry process and wet process, respectively, and two sections with asphalt modified by SBS and SSBR polymers.

The structure of each section was composed of granular base thicknesses varying between 0.25 and 0.30 m, on which a RAP-stabilized base was placed, which consisted in blending existing granular bases with RAP obtained from the test section, with a thickness of 0.10 m. An asphalt mix of 0.07 m thick was placed over the stabilized base, for each type of asphalt cement. For the construction of the sections with CRM asphalt, only steel-cylinder compacting equipment was used, as recommended by the specifications in the literature (Caltrans, 2003). It is important to mention that the expectations for the design and construction of the section was to observe its deterioration during a one-year period, that is, the section was designed for an estimated service life of one year with the existing traffic conditions on that road. The traffic for one year was estimated in 1x106 equivalent axles of 8.2 tons.

In the first stage, the test section performance was studied during one year. In the first year, measurements were made to establish the evolution of potential failures and deteriorations in each section, determination of traffic volumes, roughness measurements (IRI), static deflections and core extractions to verify the rheology of asphalt cements, advanced measurements every three months during the first year. Likewise, the aim was to make a full-scale verification of the results obtained in the laboratory studies, which were consistent in the rheological behavior of the asphalt rubber and the mechanical behavior of the mixes made with asphalt rubber (Universidad de Los Andes, 2002) (Universidad de Los Andes, 2005), (Martínez et al., 2006a), (Martínez et al., 2006b).

Figure 4 and Figure 5 show the cracking density and the surface condition of the section with CR and with SBR polymer. Figure 4 shows that the section with conventional asphalt AM80100 presented the highest cracking density after four (4) years in service. The CRM asphalt through the wet process had a performance similar to asphalts modified with polymers, which demonstrates that it is possible to obtain blends with a performance comparable to the mixes modified with polymers, through this eco-sustainable technique.

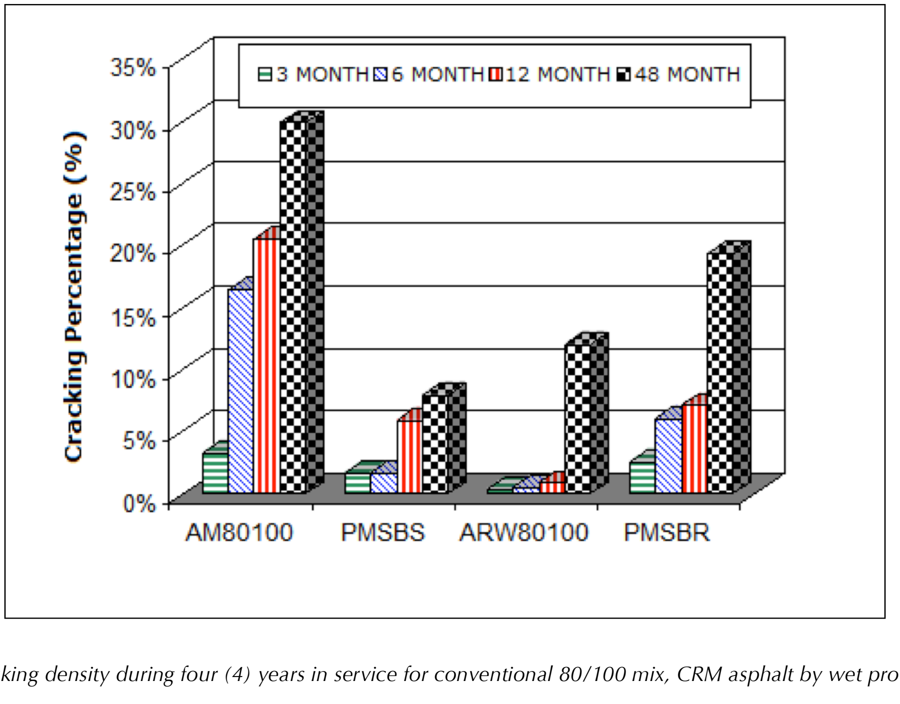

Figure 4. *Cracking density during four (4) years in service for conventional 80/100 mix, CRM asphalt by wet process, and modified with polymers*

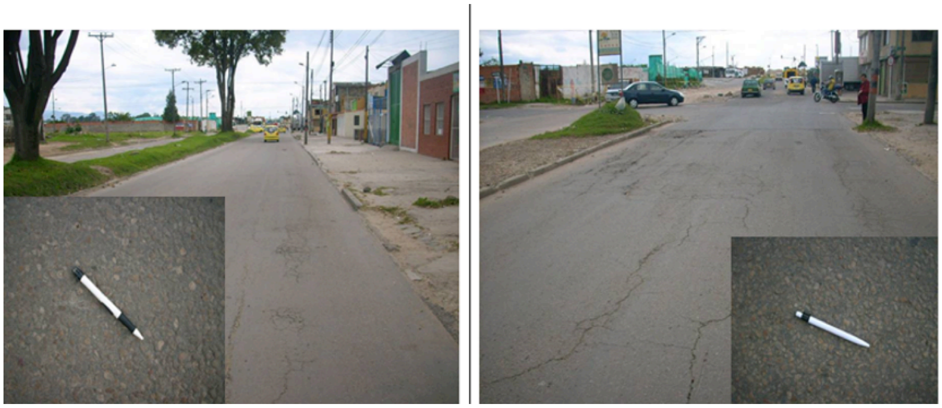

Figure 5. *Surface condition after four years, section with CRM (VH) to the left and section with SBR polymer to the right*

2.3 Development of the Technical Specification and Implementation

As a result of all the experimentation undertaken in different stages, a technical specification was developed for the city of Bogota: Section 560-11 dealing with "Hot asphalt mixes with crumb rubber modified asphalt through wet process" (Urban Development Institute of Bogota (IDU) 2011). The specification considers the viscosity criteria used during the studies, within the range of 1.5 and 3.0 Pa-s at 163°C, minimum penetration grade of 40 dmm to 70 dmm, and a softening point of minimum 52°C. In relation to the grading used in the aforementioned studies, open-graded mixes are proposed instead of dense mixes. This modification is included in accordance with the experiences at global level, which use "Gap-graded" mixes that have shown a better performance and better manageability than dense mixes (Rubber Pavement Association 2011).

In 2011, the district government of Bogota passed the Resolution No. 6981 of December 27, 2011 "Through which guidelines are issued for using used tires and non-compliant tires in the Capital District"; in article 4, this Resolution establishes the following liability:

"As of the second semester of 2012, every person executing and promoting constructive processes for infrastructure works of the urban transport of the Capital District shall foresee the use of materials resulting from used tires or non-compliant tires, in a percentage not lower than 5% of square meters per each works contract, with the exception of those having studies and designs that were approved prior to the entry into force of the present resolution.

The percentage addressed in this article will annually increase by five (5) percent units until reaching 25%, and in any case, these constructive processes shall be reported within the first fifteen (15) days of the months of June and December of each year to the District Secretariat of Environment by means of the form provided for this purpose. The first report shall take place in June, 2013".

It was precisely this resolution that allowed mixes modified with scrap tires to be massively applied in different maintenance contracts for the road network of Bogota. According to the Bulletin of recycled crumb rubber of February 2015, to date, 14,836 m3 of CRM mix have been placed, thereby reusing a total of 51,929 tires (see Table 9).

Table 9. *Statistics of the total amount of CRM asphalt mix*

Year	*Total Amount of Applied Mix m^2*	*Asphalt Mix with CR m^2*	*Asphalt Mix with CR m^3*	*Total Used Tires*
2011	-	-	*677,78*	*2372,23*
*2012**				*0*
2013	*148874,49*	*24144,01*	*2518,81*	*8815,84*
2014	*421620,19*	*93876,94*	*11640,31*	*40741,1*
Total	*570494,68*	*118020,95*	*14836,91*	*51929,18*

Source: Adapted from the (Urban Development Institute of Bogota, 2015) [8]

2.4 Incentives and Built Sections

Since 2012, and with the aim of encouraging the application of this eco-sustainable technology, the IDU has included in the public bid conditions, for the purpose of qualifying the evaluation factor called QUALITY, an additional value for bidders who commit themselves to: "Use materials resulting from used tires or non-compliant tires for asphalt pavement activities, in a 5% proportion or more of the total square meters (m^2) of the project to be built, and additional to the minimum required". Thus, it complies with the Resolution No. 6981 of 2011, and guarantees an additional 5% minimum in the application of CRM mixes. At domestic level, and motivated by the positive results of the experience in the Colombian capital, the National Roads Institute (INVIAS 2012) has established specifications for the application of CRM mixes in the entire national territory, which is a great step to achieve the sustainability of the national road network. Currently, many of these sections are part of the institutional followup program of full-scale pavement test sections in order to develop deterioration models that allow planning and improving the city's pavement management system.

3. Conclusions

The present work described different stages addressed by the IDU to achieve the adequate and correct application of mixes improved with CR. The model adopted by the IDU can serve as an example for administrations or governments to implement new maintenance and/or rehabilitation techniques, but most of all, techniques that are friendly with the environment.

The implementation of this eco-sustainable technology has involved the institutional effort for several years, going through different stages of research and development, which has been successful due to the strong technical support of the academia, the technical staff of the public sector and the road construction association.

The adaptation of this technology to the Colombian environment is contributing with a solution to the disposal of a solid waste that is difficult to eliminate, thereby contributing to the preservation of the environment and, at the same time, by producing a high-performance material that will entail important savings in maintenance and conservation costs. From the social point of view, it has allowed to open a new production sector and create employment; for example, the tire gathering chain and the creation of the tire grinding industry which did not exist in Colombia some years ago.

All of these advantages contribute to supporting the three pillars of sustainability: economy, environment protection and social benefits, to achieve a sustainable road infrastructure.

Future development stages should involve preventive maintenance techniques such as surface treatments based on CRM asphalt mixes; for example, chip seals and stress absorbing membranes.

4. References

Caltrans (2003), *State of California Department of Transportation- Asphalt Rubber User Guide.*

Instituto de Desarrollo Urbano de Bogotá (2015), *Boletín de grano de caucho reciclado de febrero de 2015. http://app.idu.gov.co/geodata/IntenasMain/tecnicas.html*

Instituto de Desarrollo Urbano de Bogotá (2011), *Especificaciones Técnicas Generales de Materiales y Construcción, para proyectos de Infraestructura Vial y de Espacio Público, para Bogotá DC. thttp://app.idu.gov.co/espec_tecnicas/espec_tecnicas_2011.htm*

INVIAS (2012), *Instituto Nacional de Vías. Especificaciones Generales de Construcción de Carreteras. Artículo 413-13. Bogotá, Colombia.*

Martínez, G., Caicedo, B., Gonzáles, D., Celis, L. (2006b) *Mechanical Properties of Hot Mix Asphalts with Crumbed rubber and others Modifiers. Proceedings of the Asphalt Rubber 2006 Conference. Palm Springs.*

Martínez, G., Caicedo, B., Gonzáles, D., Celis, L. (2006a), *Rheological Behaviour of Asphalt with Crumbed Rubber and other Modifiers. Proceedings of the Asphalt Rubber 2006 Conference. Palm Springs.*

Rubber Pavement Association (2011), *Asphalt-Rubber Standard Practice Guide http://www.rubberpavements.org/Library_Information/AR_Std_Practice_Guide_20111221.pdf.*

Universidad de Los Andes (2002), *Instituto de Desarrollo Urbano de Bogotá, Estudio de las mejoras mecánicas de mezclas asfálticas con desechos de llantas, Bogotá D.C.*

Universidad de Los Andes (2005), *Instituto de Desarrollo Urbano de Bogotá D.C., Segunda fase del estudio de las mejoras mecánicas de mezclas asfálticas con desechos de llantas – Pista de Prueba contrato 306-03, Bogotá D.C.*