Evaluation of an Alternative Gradation of Crumb Rubber on Binders and Asphalt Hot Mixes

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ABSTRACT: This paper presents an experimental evaluation regarding the modification of one Colombian Asphalt Binder (CAB) by wet process by using an alternative crumb rubber gradation. Currently in Colombia there is only one supplier with the capacity of grinding in Industrial manner waste-tire. However, the production is addressed from industries not related to transport. In addition, ground tire particles produced by these Companies are coarser than that of recommended by the California Department of Transportation (Caltrans) and Arizona Department of Transportation (ADOT), size below sieve No.30 (595µm).There is in Colombia, another way to obtain crumb rubber, by mean of the tire recycling companies, who retread the tire crust, generating as a result crumb rubber. The gradation obtained after this process can be compared with that of ADOT. The modification of one CAB with this gradation is the aim of the present document. To study the effect of this alternative gradation on a CAB, an experimental program was developed, which consisted of adding to the binder, three percentages in weight of rubber 10, 14 and 18% (w rubber/ w binder). A physical characterization was carried on the binder which included basic tests such as: penetration and ring and ball, and apparent viscosity (Brookfield apparatus.) Adherence tests for determining the adherent coating on coarse aggregate were made. The mechanical evaluation on the mixes was carried out applying monotonic loads by means of Marshall, indirect tension test.. Acoustic properties were measured according to the ISO 10534-2. The results shown that the alternative crumb rubber gradation can be a fine option to modify CAB, also an improvement can be seen on the adherence properties or water susceptibility resistance. Regarding acoustic measurements, it can be observed that noise absorption is significantly better in some specific frequency ranges.

KEYWORDS: *asphalt rubber, crumb rubber, adherence test, acoustic properties, alternative gradation.*

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1. Introduction

The crumb rubber is a well established industry recognized internationally, however its potential has not been recognized in Colombia. Several years ago, the Urban Development Institute published the first technical specification to applied crumb rubber binders on construction and maintenance works on the highway networks for Bogotá. However, the number of suppliers of crumb rubber and crumb rubber binders is almost nonexistent, hence the application of crumb rubber binders on maintenance work have been low. Currently in Colombia there is only one supplier with the capacity of grinding in Industrial manner waste-tires. However this is conducted by industries not related to transport.

This paper presents an experimental evaluation regarding the modification of a Colombian Asphalt Binder (CAB) by wet process by using an alternative crumb rubber gradation.

In addition, ground tire particles produced by these Companies are coarser than that of recommended by the California Department of Transportation (Caltrans) and Arizona Department of Transportation (ADOT), size below sieve No.30 (595µm). On the other hand, crumb rubber can also be obtained from tire recycling companies. These companies recycle the tire crust, generating as a result crumb rubber. The gradation obtained after this process can be compared with that of ADOT. The modification of the CAB with this gradation was the aim of the present document. To study the effect of this alternative gradation on the CAB, an experimental program was developed, which consisted on adding to the binder, three percentages in weight of rubber 10, 14 and 18% (w rubber/ w binder). A physical characterization was carried on the binder which included basic tests such as: penetration and ring and ball, and apparent viscosity (Brookfield apparatus). Adherence tests for determining the adherent coating on coarse aggregate were made. The mechanical evaluation on the mixes was carried out applying monotonic loads by means of Marshall, indirect tension test. Acoustic properties were measured according to the ISO 10534-2. All the experiments were carried out on the Laboratory of the Civil Engineering Department of the Universidad Piloto de Colombia and the Acoustic measured performed on the Colombian Society of Acoustic.

2. Scope

The scope of the present study is to evaluate the feasibility of using an alternative crumb rubber gradation in order modify Colombian asphalt binders.

3. Material and Experimental Methods

3.1. *Asphalt Binder and Crumb rubber*

A conventional asphalt binder with a penetration grade of 60-70 (mm/10), from the Barrancabermeja refinery (B60/70) was used in order to prepare the asphalt rubber binder. B60/70 has been classified in a previous study as a PG 58 – 16 (Martinez et al., 2006). Table No.1 presents the results of physical property characterization tests of the B60/70.

Table 1. *Physical properties of B60/70*

Binder	Ductility	Penetration	Softening Point	Density	Loss mass
	[25ºC]	[25ºC, 100 g, 5 s]		[25ºC]	
	ASTM D113	ASTM D5	ASTM D 36	ASTM D70	ASTM D2872
	[cm]	[1/10 mm]	[ºC]	[g/cm³]	[%]
Original asphalt binder					
B60-70	> 100	58	53	1.02	-
RTFO residue					
B60-70	> 100	54	59	1.03	1.00
RTFO+PAV residue					
B60-70	7.75	18	66.9	0.99	-

As was mention on the paragraph above, in Colombia, there is only one supplier with the capacity to grinding in Industrial manner waste-tires. However this production is not associated to transport industries. In addition, tire particles produced by these companies are coarser than those recommended by the California Department of Transportation (Caltrans) and Arizona Department of Transportation (ADOT). As it was mentioned before, crumb rubber can also be obtained from tire recycling companies. These companies recycle the tire crust, generating as a result crumb rubber. However, these materials have not been evaluated as a potential modifier to produce asphalt rubber (Figure 1). Two companies were evaluated; Entalladora and Repesados, as can be seen on Table 2, the grain size distribution are quite similar, so that, the experimental phase was carried out only using the sample from the Entalladora.

Figure 1. Crumb rubber process on tire re-using plant

Table 2. *Grain size distribution of crumb rubber used and grading envelope specified by ADOT*

Sieve Size		% Passing			
Inch	mm	ADOT		Enllantadora	Repesados
# 4	4,75	100	100	100,0	99,2
# 8	2,36	100	100	98,9	94,6
# 10	2	100	100	97,4	88,8
# 16	1,18	65	100	73,3	48,6
# 30	0,6	20	100	34,6	15,1
# 50	0,3	0	45	8,0	1,7
# 200	0,075	0	5	0,0	0,0

3.2. Hot mixes asphalt - HMA

In order to assess the mechanical performance of the modification of the conventional asphalt binder with crumb rubber a dense graded mix was manufactured. A HMA MDC-2(which means Dense Hot Mix type 2, in Spanish) was chosen since it is one of the most implemented mixture on highways rehabilitation activities in the Colombian context. The gradation of HMA MDC- 2 and design parameters are shown on Table 3 and Table 4.

Table 3. *Grain size distribution of HMA type MDC-2*

Sizes		MDC-2
Inch	mm	%Passing
¾	19	100
½	12,5	87,5
3/8	9,5	79
No. 4	4,75	57
No. 10	2	37
No. 40	0,425	19,5
No. 80	0,18	12,5
No. 200	0,075	6

Table 4. *Mix design of HMA*

HMA	Asphalt (%)	Bulk Specific gravity	Va (%)
Control	6	2,1	5,2
HMA-10%CR	6	2,12	5,1
HMA-14%CR	6	2,15	5
HMA-18%CR	6,1	2,16	4
HMA-20%CR	6,3	2,18	4

3.3. Experimental program

3.3.1. *Asphalt rubber modification*

The mixing process was carried out in a metallic reservoir, which had an internal oil thermal bath. Agitation energy of 700 rpm was applied during the whole mixing process. The mixing temperatures were 155ºC with a digestion time of 25 min. Both mixing temperature and digestion time were selected based on a previous comprehensive study (Martinez et al, 2006). These temperature conditions enhanced the behavior of the Colombian asphalt binders (Martinez et al, 2006)..

In order to modify the conventional asphalt binder, 4 content of CR were used; 10%(stands as ARB10), 14%(ARB14), 18%(ARB18) and 20%(ARB20). For each percentage a physical a characterization was carried out, involving the following tests:

a. Penetration – ASTM D5;
b. Softening point -- ASTM D 36;
c. Rotational viscosity – ASTM D 4402;
d. Adherence tests: for determining the adherence between the aggregate and the binder - I.N.V. 140 / 2007.

3.3.2. *Asphalt hot mix mechanical performance*

The mechanical performance on hot mixes asphalts was evaluated by means of the Marshall Stability (AASHTO T 245) and the Indirect Tension Strength (Brazilian Test - NLT-346/90).

3.3.3. *Acoustic absorption - ISO 10534-2*

The acoustic performance was evaluated applying the Standard ISO 10534-2, by using the absorption coefficient (∞). In this method, a cylindrical specimen is mounted at one end and a speaker is mounted on the other end (Figure 2). A sound pulse is generated and amplified with a sound wave at 20 Hz – 10 kHz into the impedance tube through the speaker. The generated normal incidence sound is propagated to the specimen that absorbs a part of the sound energy and the remaining energy is reflected back. The incident and reflected sound wave amplitudes are captured by the two microphones. Five repeated measurements were taken for each specimen. An Audio-card Mobile Pre-M Audio and two microphones Behringer ECM8000 were used to capture the reflected signal. The Sound absorption was calculated by using Matlab®Mathworks. The dimensions of the measured sample were 100 mm diameter and 70 mm height.

Figure 2. *Impedance tube for Sound Absorption Testing at Colombian Society of Acoustic (A); (1) Sample holder, (2) Impedance tube, (3) Microphone, (4) Speaker, (5) Data acquisition card, (B) HMA sample inside the tube.*

4. Results and Discussion

4.1. Influence of the crumb rubber on penetration and softening point test

Figure 3, shows the effect of the crumb rubber content on the penetration test of control and asphalt rubbers binders. By the addition of the crumb rubber into the conventional asphalt binder B6070 according to the experimental program exposed over, the penetration decreased 20 mm/10 until a value of 47 mm/10 for the CR Binder with a 10% rubber. The penetration keeps the decreasing tendency until a value of 37 mm/100 for ARB-18%. All these values fulfill the requirements established on the ASTM D6114-97 (See Table 5), which suggests a range of 25-75 mm/10.

Table 5. *Asphalt Rubber Binder requirements according to ASTM D 6114/97*

Tests	Requirements	
Viscosity Brookfield @175°C: cP (ASTM D2196)	Min. 1500	Max 5000
Penetration @25°C: 1/10 mm (ASTM D5)	Min. 25	Max 75
Resilience @25°C: % (ASTM D 5329)	Min. 20	
Softening Point, Ring&Ball: °C (ASTM D36)	Min. 54.5	

Regarding the softening point test, an increase is exhibited on the softening temperature for each ARB. The temperatures changes from 52 °C for the ARB10% to 56 °C for the ARB18%. This behavior shows the known effect of the rubber content on the consistency of asphalt binder-AB that has been reported in the literature (Neto *et al.*, 2006, *Bahia., et al* 1994).

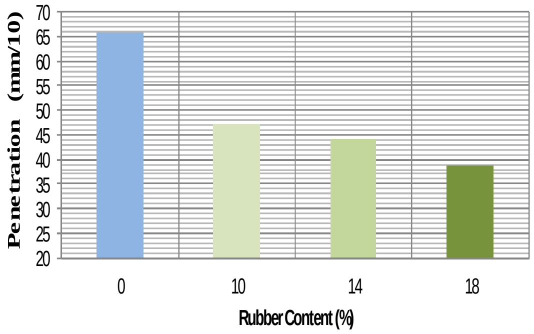


Figure 3. *Penetration of samples control and asphalt –rubber binders*

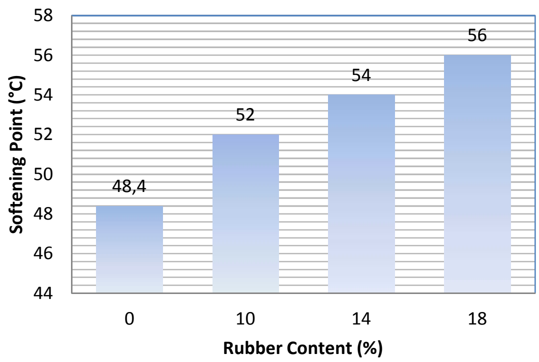


Figure 4. *Softening Point of samples control and asphalt –rubber binders*

As shown on the Figure 5, measurements to evaluate the rotational viscosity were carried out by using rotational viscometer type Brookfield Model RVTDV –II with the spindle No. 29 at 20 rpm. Again, the ASTM D6114 establishes a range between 1500cP and 5000cP at 175°C. As can be seen on the Figure 5, considering the before mentioned conditions for the AB60-70 modified with the alternative gradation, the required specifications were not achieved. However, on the threshold comprise from 10 to 20% of rubber content, under the same conditions, the presence of rubber showed an increase on the apparent viscosity. The influence of crumb rubber on the asphalt binder chemical structure has been widely described on the literature (Bahia and Davis 1994; Airey *et al.*, 2003; Xiao *et al.*, 2006), the increment in the level of viscosity (consistency) is explained by the interaction between rubber particles and asphalt which is characterized by the fact that the asphaltenes and light fractions of the conventional asphalt binder and the rubber particles interact to form a gel coated particle (Neto *et al.*,2006, Holleran and Reed, 2000).

It is importance to underline that the modification undertaken on this research was performed following the comprehensive study regarding the modification of the Colombian asphalt binders specified by the Urban Development Institute (Bogota Urban Development Institute, 2002, Bogota Urban Development Institute, 2005, Martinez *et al.*, 2006(a,b,c), Martinez *et al.*, 2009), in which the modification process was developed with an optimal combination of 25 min, 18% rubber content and 155°C of digestion time using different agitation energies (700 – 1200 rpm). The viscosity values outside the standard parameter is attributed by the authors to the short digestion time on the modification process, however the main reason for choosing a short digestion time (25 min) is to avoid the aging process and volatilization of the light fractions, since the Colombian asphalt binders are characterized for its high susceptibility to temperature and high volatilization of light fractions. Further studies should involve higher digestion times in order to verify the accordance with the standard and a specific control of the aging rate and chemical impact.

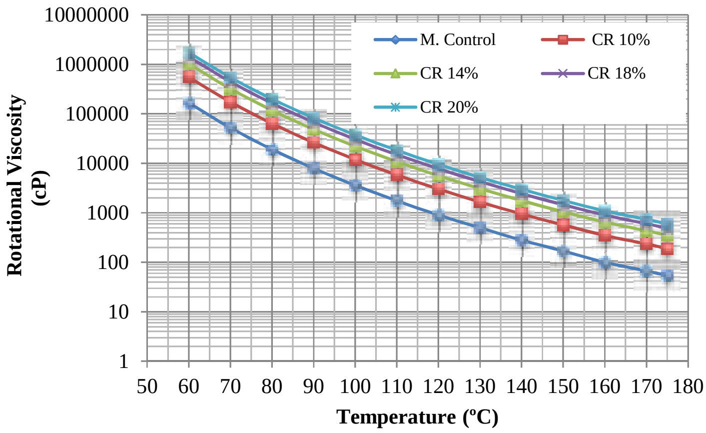


Figure 5. *Rotational viscosity samples control and asphalt–rubber binders, Spindle No. 29, 20 rpm.*

4.2. Asphalt Adherence in aggregates surface I.N.V – 140 - 07

In order to verify the impact of the content of asphalt rubber on the adherence and stripping properties, a simple test was undertaken. The test consist of a set of aggregates located on a plate with a 2 mm asphalt film, the plate is placed in a convection oven at 60 °C during 24 h. Afterwards distilled water is added to the plate, the sample is left for 4 days at ambient temperature. A visual evaluation on the aggregates face is conducted in order to determine the percentage of the aggregates face with asphalt coat (Figure 6).

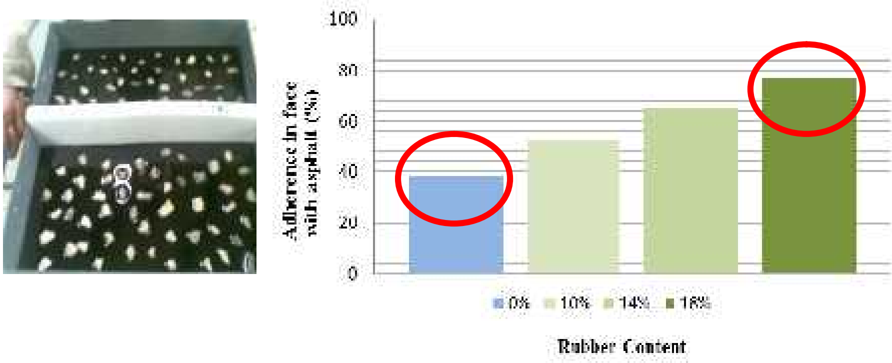


Figure 6. *Asphalt Adherence in aggregates surface*

It is well known that adhesion at the interface between bitumen and aggregate is one of the principal functional properties to guarantee durability of asphalt mixes. Furthermore, the moisture damage is one of main weakness of the asphalt hot mix, which reduces the life cycle of a pavement exhibiting short term distress such as ravelling and weathering (Little et al 2002, Epps et al, 2001). Some strategies applied to improve the resistance to moisture damage can be the addition of hydrated lime, liquid anti-stripping agent or the polymer modification of a binder. Therefore is an important characteristic that have been addressed in the present study. As can be seen on Figure 6, the content of crumb rubber has a significant effect on the moisture susceptibility, or better on the adherence between the aggregates and binder.

In the specific case of the aggregates used, the moisture damage resistance has been improved passing from a percentage on aggregates face with asphalt of almost 40% to 75% with the asphalt rubber content of 18%. According to the results obtained one can observed that the asphalt rubber increased in a significant manner the aggregates – binder adherence.

4.3. *Performance of the Hot mixes asphalt*

As was mentioned on the experimental program above, two tests were performed in order quantified the mechanical performance. Both Marshall Stability and Indirect tension Test are monotonic test which means that these has constant application velocity when the load is applied. Figure 7 shows the behavior of the control and the modified HMA. The impact of the modification with crumb rubber is reflected with an increase on the marshal stability, surpassing even the value of 2000 Kg for the sample with the 20% of rubber content. The effect of the modification process is also noticeable on the mix with the CR content of 10%.

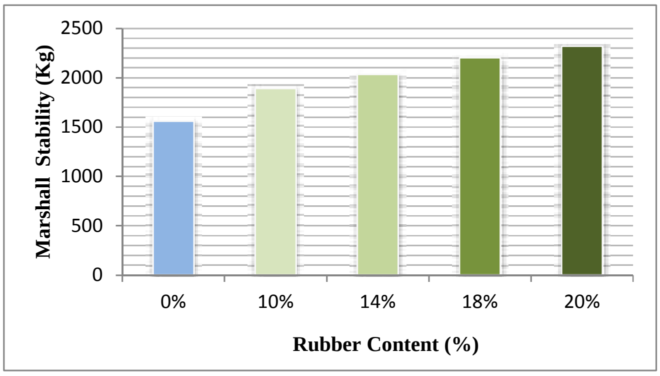


Figure 7. *Marshall Stability of hot mixes asphalt used*

Furthermore of marshal tests, the Indirect Tension Strength – ITS, were evaluated using Marshal Specimen with 100mm diameter . The test procedure was carried out according to the NLT-346/90. Figure 8 shows an image of the test execution, and Figure 9 shows the results obtained. The crumb rubber influence on the indirect tension performance is significant, as the CR content increases the ITS takes the same tendency, it can be explained on the fact, that the increase on consistency test (penetration, softening point, Rotational viscosity) is reflected on the mechanical performance of the CR HMA (Garrick and Biskur, 1990), while the effect of the crumb rubber on the HMA performance have been studied finding results below the standard requirements (Mohammad and Cooper., 2009, Ryu *et al.*, 2009).

Figure 8. *Indirect tension test for AR HMA*

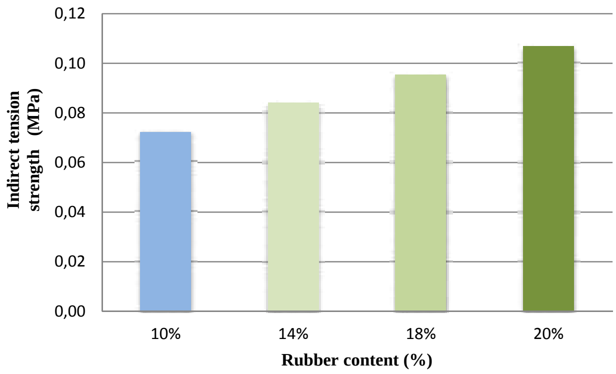
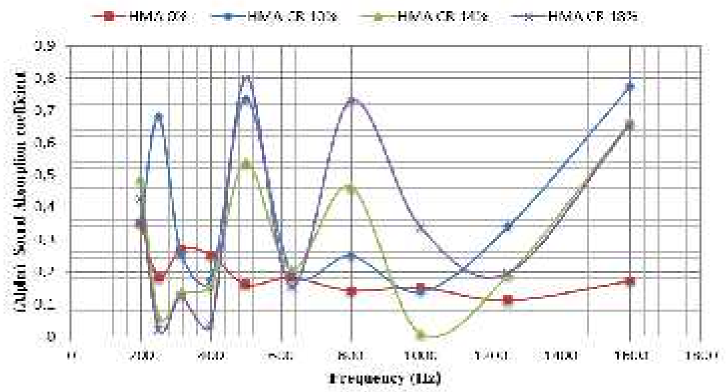


Figure 9. *Indirect tension test results for AR HMA at 25°C*

4.4. Acoustic absorption of the HMA - ISO 10534-2

After determining the acoustic absorption capacity of each HMA in the frequency range between 200 Hz to 1600 Hz (Figure 10), it can be appreciated that all of the CR HMA exhibited higher sound absorption coefficients on specifics range of frequencies. Before to present the correspondence analysis, must be underlined that all the HMA had the same grain size distribution, and similar voids content (4 – 5%), so that the differences is based fundamentally on the binder. Therefore for the different percentage of crumb rubber (10, 14 and 18%), samples presented similar peak of absorption, which were located in between 400 and 600 Hz, 700 and 900 Hz. In addition, for greater frequencies of 1200 Hz, the rubberized samples exhibited the same trend toward higher Sound Absorption Coefficients. The highest absorption capacity was shown by the HMA-18%CR reaching Alpha coefficient near to 0,80 on 500 Hz. In general the Crumb Rubber-HMA showed a good acoustic performance with respect to the control mix.



igure 10. *Sound Absorption Coefficient for AR Hot mixes at different frequencies*

5. Summary and Conclusions

This paper presents the results obtained concerning the modification of a conventional asphalt binder 60-70 penetration graded with an alternative grain size distribution. The modification process of the asphalts rubber was carried out using the known “wet process”. The modification process was achieved by applying agitation energy of 700 rpm, a digestion time of 25 min at a low modification temperature 155°C, while the rubber content added were 10%, 14%, 18% and 20%. On the binder a series of penetration, softening point, rotational viscosity tests were perform, while for the HMA Marshal Stabilities and Indirect Tension tests were executed. Finally the sound absorption capacity was measured. From these results, and based on the test conducted the following conclusions were drawn:

According to the binder characterization, the CR addition generated higher softening points and higher rotational viscosity, while for the penetration test implied lower penetration values; all these results demonstrated a stiffer effect on the modified binder. This effect have been described in the literature as the interaction between rubber and asphalt particles which is characterized by the fact that the asphaltenes and light fractions of the conventional asphalt binder and the rubber particles interact to form a gel coated particle (Bahia *et al.*, 1994, Neto *et al.*, 2006). However the results of the rotational viscosity did not fulfill the requirement established on the ASTM D6114 (viscosity 1500 cP to 5000cP at 175°C), this fact may be related to the low temperature and digestion applied, which could not be the best conditions to modify this specific binder. Furthermore, the adherence test applied to qualitatively measure the bound between aggregates-binder, showed interesting results, increasing the adherence from 40% (control binder) to 75% (ARB18).

Regarding the mechanical performance of the CR HMA, the higher consistency shown on the binder characterization was reflected on the mixes behaviour, the effect of the CR addition showed higher Marshall stabilities and higher ITS values in a direct relationship with CR content.

Acoustic properties measured in the study showed that all the crumb rubber mixes presented similar peak of sound absorption, which were located in a range between 400 and 600 Hz, 700 and 900 Hz. In addition, for greater frequencies of 1200 Hz, the crumb rubber hot mixes exhibited the same trend toward higher Sound Absorption Coefficients.

Further studies with this CR gradation should consider rheological test involving higher digestion times and modification temperatures for binders. For HMA dynamic mechanical tests (fatigue, rutting, and stiffness modulus) should be evaluated in order to have a complete characterization of the Crumb Rubber Binders produced with this new gradation.

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