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Effect of aging on the physical-mechanical characteristics of an asphalt mixture with rubber

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Abstract. This paper evaluated the physical-mechanical characteristics of two asphalt mixtures. One mix with conventional asphalt and the other with asphalt modified with recycled rubber grain. For this purpose, the asphalt mix designs were made by means of the Marshall methodology. Subsequently, asphalt mixtures were manufactured to analyze the action of monotonic loads (indirect tensile strength) and dynamic loads (resilient modulus). Previously, each type of asphalt mix was subjected to short- and long-term aging conditions, following Aastho guidelines. It is concluded that the incorporation of recycled rubber grain makes the changes in mechanical properties with aging not very noticeable in relation to mixtures without this material.

1. Introduction

Asphalt mixtures are frequently used as wearing course for pavements; however, asphalts are prone to degradation caused by vehicle traffic and climatic factors; among the phenomena that affect the durability of asphalt mixes, one of the most studied is aging. This phenomenon is a slow physicochemical process that consists of the loss of the most volatile fractions of the asphalt, leading to hardening and a decrease in the elastic recovery of the mixes. Therefore, the production of more durable mixes requires laboratory studies and the addition of additives that slow down this process. In this sense, in recent years, several additives have been introduced to asphalt binders in order to improve their properties and the performance of the mixtures.

The use of crumb rubber modifier (CRM) from recycled tires has been widely used as a modifier of asphalt mixtures. Despite not being a recent technique, studies are still required to improve the technology [1]. In the case of Colombia, the “Instituto de Desarrollo Urbano (IDU)” in Bogotá, Colombia, and the “Instituto Nacional de Vías (INVIAS)” at the national level have made great efforts to implement the use of asphalt mixtures modified with CRM, seeking to identify their limitations and potential advantages to be applied in the road network of the city of Bogotá, and in general in the Colombian territory [2]. According to [3], three main technologies involving the use of CRM in the production of mixes are distinguished in the literature: the wet process (ARwet), the dry process (ARdry), and the terminal mix process (ARtb). In the dry process, the granulated rubber is mixed with the aggregates before the asphalt is added. The wet process consists of adding CRM and the base asphalt, with the purpose of producing a more consistent asphalt, as a result of the chemical reaction between the asphalt with 15 to 22% CRM [4]. Several authors [1,2,5–8] report that the use of wet CRM considerably increases the mechanical performance of the mixes compared to conventional mixes. The



main advantages of incorporating asphalt with CRM in the asphalt mixture are greater resistance to fatigue and aging, as well as reduced permanent deformation [9–13]. In addition, the use of CRM in asphalt mixtures provides a final and environmentally appropriate disposal of the large quantities of used tires.

In view of this situation, the main objective of this article is to compare the physical-mechanical properties of an asphalt mix modified with CRM with respect to a conventional mix (control). For this aim, the asphalt mixtures were designed and subjected to short- and long-term aging effects. Subsequently, the mechanical performance was evaluated by means of resistance to monotonic and dynamic loads.

2. Methodology and materials

The research methodology is separated into four stages; (I) the first corresponds to the physical characterization of the asphalt materials (AC 60-70 and AC-CRM) and the stone aggregates, according to the protocols established by INVIAS for the manufacture of asphalt mixtures in Colombia; (II) the second stage concerns the design of asphalt mixes using conventional asphalt AC 60-70 for the control mix and modified asphalt type AC-CRM for the study mix. For this purpose, the Marshall test was used to determine the optimum asphalt content for each mix; (III) established on the optimum content for each mixture, Marshall type test specimen were made for both mixtures, which were subjected to short- and long-term aging. (IV) Finally, the physical-mechanical properties of the mixtures were evaluated by means of indirect tensile strength (ITS) and resilient modulus (MR) tests, in order to analyze the influence of aging.

2.1. Marshall test

For the design of the HMA-19 Control and HMA-CRM mixes, four probable asphalt contents were selected to analyze the volumetric composition and Marshall strength parameters. The Marshall test was performed following the protocols of ASTM D6926. For the HMA-19 Control mix, Marshall-type test specimen were made using 4.5%, 5.0%, 5.5% and 6.0% asphalt contents. For the HMA-CRM mix, the asphalt contents were 6.0%, 6.5%, 7.0% and 7.5%. This is because the modified asphalt has a higher viscosity and consequently a greater amount of material is needed to guarantee the coating of the aggregate particles, in reference to conventional asphalt AC 60-70. Three test specimens were made for each asphalt content. That is a total of 12 test specimen for each type of asphalt mix. Each briquette was made with a mass of asphalt mix corresponding to 1200 grams. The manufacturing temperature ranges were 146 °C to 152 °C and 165 °C to 175 °C and the compaction temperatures were 136 °C to 140 °C and 137 °C to 143 °C for the HMA-19 control and HMA-CRM mixes, respectively.

The test specimen was compacted by impact with a Marshall-type hammer through the application of 75 blows per each side. After the completion of each briquette, the volumetric composition was determined: air voids (Va), voids aggregate mineral (VAM) and voids filled asphalt (VFA). Subsequently, each briquette was subjected to the action of a monotonic load in the universal machine, applying a deformation speed of 48 mm/minute until rupture. This was done in order to determine the Marshall stability (S) and flow (F). Previously, the test specimen was conditioned at 60°C in a water bath for a time interval between 30 and 40 minutes. Finally, the optimum asphalt content for each mix was determined according to INVIAS specification protocols, which were used in the following stages.

2.2. Simulation of short- and long-term aging

After obtaining the optimum asphalt content for the HMA-19 Control and HMA-CRM mixes, Marshall-type test specimen were manufactured following the procedure described in ASTM D6926. short-term oven aging (STOA) and long-term oven aging (LTOA) were then simulated following the protocols of the AASTHO R30 standard. For the short-term simulation, the asphalt mixtures in their loose state are placed in an oven at 135 °C for two to four hours. For the long-term simulation, the compacted asphalt mixtures are placed in an oven at 85 °C for 120 hours.

2.3. Evaluation of the physical mechanical properties of the mixtures

The physical-mechanical properties of the HMA-19 control, and HMA-CRM mixtures were determined by indirect tensile strength (ITS) and resilient modulus (RM) tests, following the protocols of ASTM D6931 [14] and ASTM D7369 [15], respectively. In the ITS test, each briquette was subjected to the action of a monotonic load in the universal machine, applying a deformation rate of 50 mm/minute until rupture. The tests were carried out at a test temperature of 25 °C. The determination of ITS in kPa was carried out according to Equation (1), where P is the maximum breaking load in N, d and h correspond to the diameter and height of the briquette in mm.

The determination of the RM was carried out in a UTM-30 universal testing machine, through the application of a 1200 N cyclic load by diametral compression on Marshall type test specimen. Five loading and unloading cycles were applied at frequencies of 10, 5.0 and 2.5 Hz and a temperature of 25 °C. For each asphalt mixture (HMA-19 Control and HMA-CRM), three tests were performed for each aging condition, for a total of 24 tests (2 mixtures, 2 aging conditions, 2 tests and 3 repetitions).

$$ITS = \frac{2000 \times P}{\pi \times d \times h} \quad (1)$$

3. Results and discussions

This segment presents the results obtained from the physical characterization of the modified asphalt, AC 60-70 asphalt and the stone aggregates used in the manufacture of the asphalt mixture. Later, the designs are presented, and physical-mechanical properties of an asphalt mix modified with CRM with respect to a conventional mix (control).

Table 1 to Table 3 show the results of the physical characteristics of the materials used, such as: CRM modified asphalt, AC 60-70, and stone aggregates. From the results found, it is possible to observe that the results comply with the requirements established by INVIAS in articles 413 and 450 for the manufacture of hot mixture asphalt [16].

Table 1. Physical characteristics of modified asphalt AC CRM.

Characteristics	Specification	Measure	AC CRM		
			Minimum	Maximum	Result
Viscosity apparent 175 °C	[17]	Pa-s	1.5	5.0	4.6
Penetration 25 °C	[18]	0.1 mm	25	75	38
Penetration 4 °C	[18]	0.1 mm	15	-	20
Softening point	[19]	°C	54.0	-	77.6
Flashpoint	[20]	°C	230	-	208
Penetration, in % respect to the original penetration	[18]	%	75	-	80

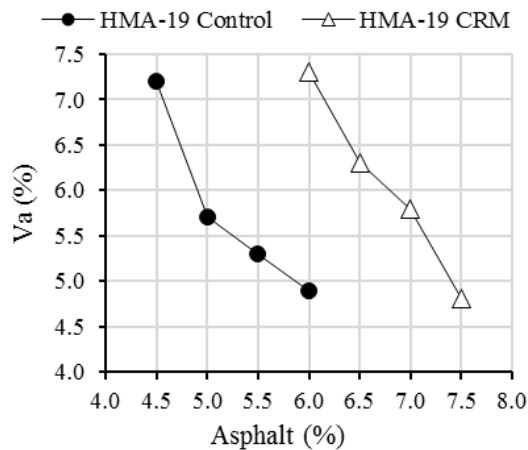
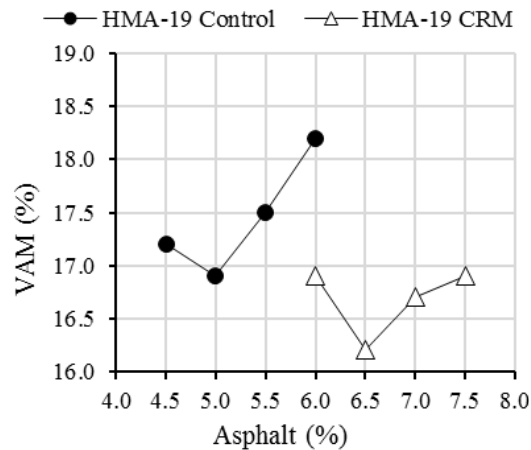
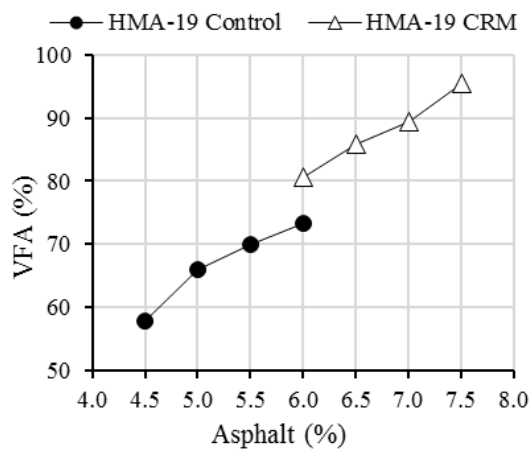
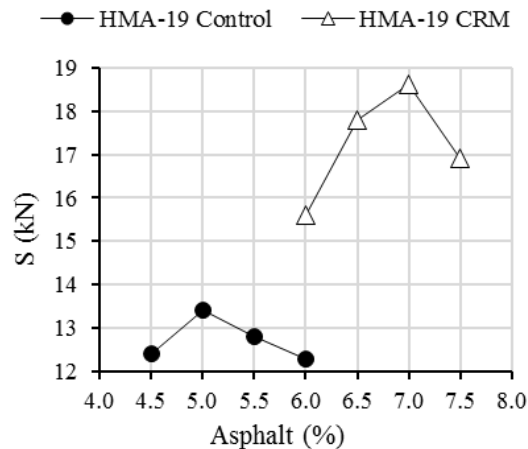
Table 2. Physical characteristics of asphalt AC 60-70.

Characteristics	Specification	Measure	AC 60-70		
			Minimum	Maximum	Result
Penetration	[18]	0.1 mm	50	70	67
Penetration index	[21]	-	-1.20	+0.60	-0.59
Softening point	[19]	°C	48.0	54.0	49.6
Specific gravity	[22]	-	-	-	1.021
Viscosity absolute 60°C	[17]	P	1500	-	2172
Flashpoint	[20]	°C	230	-	302
Ductility	[23]	cm	100	-	135
Loss of mass	[24]	%	-	0.8	0.4
Penetration, in % with reference to the original penetration	[18]	%	50.0	-	57.5
Increase of softening point	[19]	°C	-	9.0	7.8

Table 3. Physical characteristics of aggregate.

characteristics	Standard	Measure	Value	Specification
Sand equivalent	[25]	%	66.0	minimum 55.0
Abrasion in Los Angeles	[26]	%	21.0	maximum 50.0
Form index	[27]	-	0.7	minimum 0.5
Soundness of aggregates by use of magnesium sulfate	[28]	%	7.0	maximum 12.0
Bulk specific gravity coarse	[29]	-	2.6	-
Bulk specific gravity saturated- surfaced-dry coarse	[29]	-	2.6	-
Absorption coarse	[29]	%	0.8	-
Specific gravity of fine aggregates	[30]	-	2.6	-

Figure 1 to Figure 6 present the results of the volumetric composition (Va, VAM and VFA) and Marshall design strength parameters (S, F and S/F) for the HMA-19 Control and HMA-CRM mixes. The optimum asphalt contents for the HMA-19 Control and HMA-CRM mixes are 5.0% and 6.5%, respectively. These contents were obtained based on the higher stiffness values of the mixes, as evidenced by the S/F ratio.

**Figure 1.** Variation of Va with asphalt.**Figure 2.** Variation of VAM with asphalt.**Figure 3.** Variation of VFA with asphalt.**Figure 4.** Variation of S with asphalt.

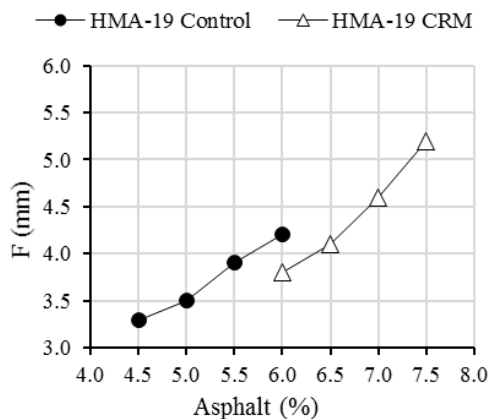


Figure 5. Variation of F with asphalt.

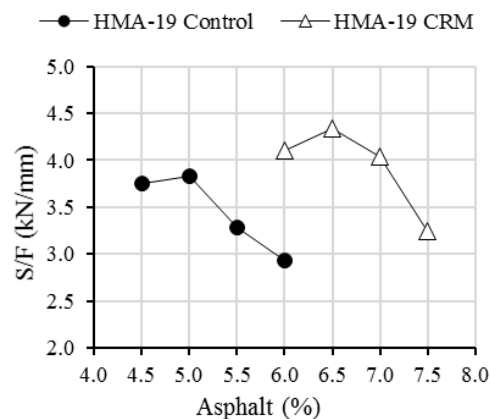


Figure 6. Variation of S/F with asphalt.

Figure 7 shows the ITS and RM results for the HMA-19 Control and HMA-CRM mixtures, previously aged in both the short and long term; from the results obtained, it is possible to evidence that the mixture with CRM presented a reduction of approximately 6.6% of ITS compared to the control mixture. These results are consistent with those obtained in the literature, given the internal reduction of cohesion and adhesion between the particles due to the presence of CRM. In addition, it is possible to evidence a non-significant reduction, which is attributed to the high optimum asphalt content of the CRM mix. With respect to the effect of long-term aging, increases in ITS of approximately 22.1% and 2.6% were observed for the HMA-19 control and HMA-CRM mixes, respectively. The control blend showed a greater variation of ITS due to the release of maltene oils (saturated and aromatic) as a result of the temperature effect during aging. On the other hand, the mixture with rubber experienced a lower variation of ITS due to the absorption of the maltene oils by the CRM during the same process.

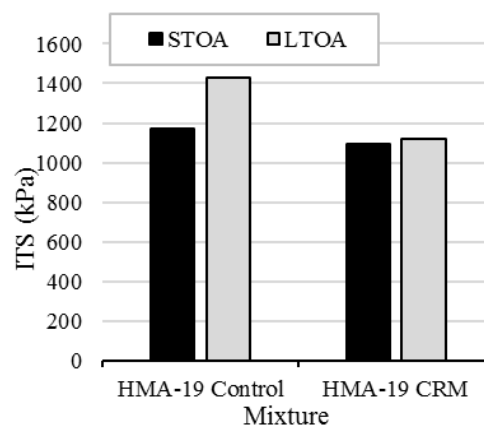


Figure 7. IST test at 25°C.

Figure 8 shows the results of the resilient modulus for the control and CRM-modified asphalt mixtures subjected to short- and long-term aging. In general, the mixtures with CRM presented lower values of RM with respect to the control mixture. This behavior is consistent with the literature, since for the same load level during the test (1200 N), the mixtures with CRM show greater elastic deformation. For both materials, there is an increase in the RM with aging. However, the control mix shows considerable increases with respect to the mix with CRM, as shown in Figure 9. This is attributed to the physical-chemical phenomena presented during the manufacturing of the modified asphalt and aging, as described in the ITS test. On the other hand, for the two mixtures, the increases in modulus are higher with the increase of the test frequency. Being higher for the control mixtures and with little variation in the mixtures with CRM.

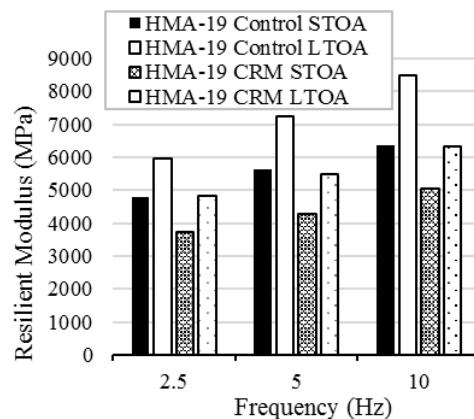


Figure 8. Test resilient modulus at 25°C.

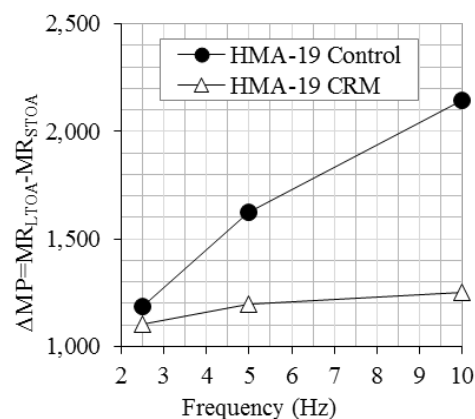


Figure 9. Increase in resilient modulus.

4. Conclusions

This work analyzed the effect of short- and long-term aging on the mechanical behavior of asphalt mixtures with and without asphalt modified with CRM. For this purpose, the Marshall, ITS and MR tests were performed. From the results, it is possible to conclude that: the decreasing effect of the indirect tensile strength of the CRM-modified mixture in relation to the control mixture is balanced by the increase of the optimum asphalt content obtained by dosing through the Marshall methodology. In addition, the indirect tensile strength experienced little variation due to the effect of aging in the mixture with CRM.

The effect of long-term aging resulted in increased stiffness in the asphalt mixture. This was observed by increases in tensile strength and resilient modulus. However, the use of CRM-modified asphalt provided smaller increases in stiffness. These behaviors are attributed to the physicochemical processes originated in the manufacturing process of the modified asphalt. In general, the incorporation of rubber provides that the changes in mechanical properties with aging are not very noticeable in relation to mixtures without this material. This provides technical evidence for the feasibility of use in paving projects, mainly in the city of Bogota, Colombia.

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