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Part 1

Pavement Performance and Design

MECHANICAL PROPERTIES OF ASPHALT-RUBBER MIXES USING SHALE EXTENDER OIL

F279m

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ABSTRACT: The purpose of this research was to study, in laboratory, the performance of three hot mix asphalt concretes: two using different crumb rubber and shale oil contents (M2: AC40 + 12% rubber + 10% shale oil and M3: AC40 + 20% rubber + 15% shale oil) and a conventional hot mix asphalt concrete (M1: AC40). The research is part of a major program comprehending the investigation on asphalt mixes using tire rubber and shale oil, as an extender agent. The asphalt concrete specimens were compacted in the optimum binder content of each mix. Mechanical properties of each Marshall compacted specimen were complementarily evaluated by the following tests: indirect tension, resilient modulus and static creep. Results of Marshall tests indicated an increase in the optimum binder content, a reduction of density and Marshall stability, and an increase in the air voids of the modified mixes. Results of indirect tension test indicated that modified mixes had a reduction of more than 50% in the resistance, in comparison with the conventional mix. Resilient modulus of M1 was about the double of mix M2 and about the triple of M3. Static creep tests indicated that mixes M1 and M3 have a good performance under 0.7 MPa tension and mix M2 under 0.4 MPa tension. Regardless the fact that both modified mixes containing crumb rubber and shale oil presented lower resistance than the conventional one, their physical characteristics are acceptable for constructing hot mix asphalt layers, on an experimental basis. The results lead to the conclusion that experimental road sections or segments may be constructed with both mixes to assess their viability in field conditions.

KEY WORDS: asphalt-rubber, shale oil, wet process, hot mix asphalt concrete

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1. Introduction

In the last few years the growing concern about the disposal of worn-out tires gave impulse to researches oriented to use recycled rubber on asphalt pavement layers. The Brazilian Resolution n. 258 of CONAMA (Brazilian Environmental National Council), from 1999, declares that tire producers shall take over the responsibility for their final destination. Since 2002 tire producers and importers are being forced to collect and put them in environmentally appropriate places, and the amount of available disposed tires, that today reaches 900 million units in Brazil [ROC 01], must begin to decrease by 2005.

One of the possibilities to use tire rubber in pavement is incorporating it in the binder for asphalt concrete. This binder is obtained by the mixture of particles of crumb rubber, usually with diameter inferior to 2.00 mm, and asphalt cement. This reaction should happen under conditions of high temperature, usually in the range from 150 to 200ºC, and high shear stresses, during a reaction time that can vary from 20 to 120 min. The amount of rubber may vary from 5 to 25%. The homogeneity of the mixture is a function of temperature and reaction time; these parameters depending, basically, on rubber content, on rubber particle size and on binder viscosity.

In the production of the asphalt-rubber the so called *rubber extender oils* can also be used, whose function is to facilitate the incorporation of the crumb rubber to the binder, resulting an asphalt-rubber of better quality. The rubber incorporation by the asphalt is a phenomenon that involves the consumption of some aromatic oil present in the asphalt, and thus increasing the viscosity of the final product. The addition of rubber extender oil can adjust the chemical composition of the binder, bringing the asphalt-rubber viscosity to acceptable levels for the use in pavements. It can be added in proportions that vary from 5 to 20% of the binder content, depending on factors as binder viscosity and content of incorporated crumb rubber. The *shale extender oil* is a type of rubber extender oil available in Brazil. It is obtained from the processing of bituminous schist and discarded tires, and is commercially named AR-5.

2. Objectives

The purpose of this research is to evaluate some mechanical properties of three hot mix asphalt mixes, made with three different binders. For the first, taken as reference, a conventional asphalt cement (AC40) is used; the two others mixes contain different percentages of crumb rubber modifier (CRM) and extender oil: AC40 + 12% of CRM + 10% of extender oil and AC40 + 20% of CRM + 15% of extender oil. The mixes were designed according to the Marshall method and the mechanical properties of each Marshall specimen were evaluated by the following tests: indirect tension, determined by static diametrical compression, resilient modulus, determined by diametrical compression with repeated load, and static uniaxial creep test. The results of this study were used to establish the viability of use of these mixes on experimental road segments.

3. Mechanical properties of crumb rubber modified hot mix asphalt concrete

In general, the commonly evaluated properties of the asphalt mixes are very sensitive to factors as binder type and content, type, maximum dimension and gradation of mineral aggregate, mixing temperature, compacting process, type, maximum dimension and gradation of rubber and other intervening factors. Under this view, some of the conclusions of studies about rubber incorporation to asphalt mixes are exclusively valid for the distinctive conditions in which they were tested, although, in many cases, improvement is verified in pavement performance.

As a non-conventional material, special care should be taken in the production of asphalt-rubber mixes, in regard to crumb rubber characteristics, mineral aggregate selection, binder choice, mix design and, also, with regard to the recommendations about mixing, placing and compacting procedures.

Some evidences of previous researches show that the use of crumb rubber in asphalt mixes can increase fatigue, rutting and skidding resistance, improve the resistance to formation of reflection and thermal cracking and reduce water sensitivity. Other studies also indicate that the asphalt-rubber can contribute significantly to the reduction of the noise attributed to the interaction between the road surface and the vehicle tires in highways, besides allowing the execution of finer asphalt overlayers and reducing the costs of maintenance and rehabilitation activities.

Some studies indicate that the Marshall stability decreases with addition of rubber [EPP 94, HAN 94], while others found increased stability or no effect [ROB 87; BRO 97]. Marshall flow may increase when rubber is added to mixes [EPP 94]; [HAN 94] or may have no effect [BRO 97]. Air voids and voids of mineral aggregate usually increase because of rubber incorporation. Little difference is noticed in unit weight for the two mix types [EPP 94]. The addition of rubber causes substantial increase of the optimum binder content. This increase is, in general, equal to the rubber content added to the binder and it can be attributed to the increase of the asphalt-rubber viscosity and of the asphalt film thickness that covers the mineral aggregate.

Researches on the influence of tire rubber on resilient modulus of asphalt concrete do not point a clear tendency. The addition of rubber can promote increase or decrease of resilient modulus, although, most of time, decrease is verified [EPP 94]. A reduction of approximately 50% in the resilient modulus (1,806 MPa of the crumb rubber asphalt concrete against 4,021 MPa of the conventional mix) was also verified [LEI 00].

Some studies show that there is not a clear tendency of the rubber influence on rutting resistance of asphalt mixes. It can increase [KRU 92, HAN 94, LEI 00], decrease [MAU 92] or give equivalent results [EPP 94] of rutting resistance in comparison with reference mixes.

The presence of tire rubber, in a general way, contributes to the increase of fatigue life of asphalt mixes [PIG 77, VAL 80, SAL 87, EPP 94]. The addition of extender oil in the asphalt-rubber mixes promoted an increment of 20,000 cycles in fatigue life for each 1% of extender oil added [OLI 00].

According to one author the tensile strength can increase or decrease when there is addition of tire rubber [EPP 94]. Another study, using AC20, indicates that there is an increase of the tensile strength of the CRM mixes in relation to the reference mix [LEI 00].

4. The experiment

4.1. Materials

The mineral aggregate used in this research was obtained from crushed basalt rock. The target gradation was the center of C gradation band specified by the São Paulo State Department of Highways [DER, 1991]. Grain size distribution and other physical characteristics of this material are shown in Table 1 and Table 2.

Table 1. *Grain size distribution of mineral aggregate.*

Sieve size (mm)	Center of C gradation (DER, 1991)
19.0	100.0
12.5	92.5
4.8	65.0
2.0	47.5
0.42	27.5
0.175	17.5
0.075	8.0

The binders used were supplied by the Unit of Trading of the Industrialization of the Schist of Petrobras (SIX-Petrobras), of São Mateus do Sul, State of Paraná. The results of the physical characterization are shown in Table 3. The extender oil used in this research is a shale oil called AR-5, produced by SIX-Petrobras.

Table 2. *Results of physical characterization of mineral aggregate.*

Properties	Test methods	Results
Bulk specific gravity of fine aggregate (kN/m^3)	DER/SP M3-61	27.792
Los Angeles abrasion, %	DER/SP M35/64	13
Adhesivity of coarse aggregate to AC40	DNER ME 78-63	Non-satisfactory
Adhesivity of fine aggregate to AC40	DNER ME 79-63	Poor
Adhesivity of coarse aggregate to AC40 + 12% CRM + 10% AR-5	DNER ME 78-63	Non-satisfactory
Adhesivity of fine aggregate to AC40 + 12% CRM + 10% AR-5	DNER ME 79-63	Poor
Adhesivity of coarse aggregate to AC40 + 20% CRM + 15% AR-5	DNER ME 78-63	Non-satisfactory
Adhesivity of fine aggregate to AC40 + 20% CRM + 15% AR-5	DNER ME 79-63	Satisfactory

4.2. Experimental method

As a preliminary step an optimum binder content was determined for each binder type, according to Marshall method [DER 91], using the compacting energy of 75 blows per face of the specimen. Each optimum binder content was chosen for air voids near 4%. All other parameters were maintained within the recommended limits. In the second phase Marshall specimens were compacted in the optimum binder content characteristic to each mix and were used to determine tensile strength, resilient modulus and parameters of uniaxial creep test.

Tensile strength and resilient modulus tests were conducted at 25ºC according to prescriptions of the adopted standards [DNE 94a; DNE 94b]. For the static uniaxial creep tests no standards were available and thus some recommendations in the literature were adopted. A temperature of 40ºC and two levels of axial tension were used: 0.4 MPa and 0.7 MPa. It was decided to apply a pre-load, corresponding to 100% of the compression load, during 2 min, followed by a rest period of 5 min, to promote the specimen pre-conditioning. Soon afterwards, the load application was run during 60 min, followed by a rest period of 15 min, during which measures of axial displacement in pre-established intervals of time were made.

6. Results

Table 4 shows the results of Marshall parameters in the optimum binder content of each mix. Figure 1 indicates a comparison of the results of Marshall tests of the three mixes evaluated in this research.

Tabela 3. *Results of physical characterization of binders.*

Properties		Test methods	AC 40	AC40 + 12%CRM + 10%AR-5	AC40 + 20%CRM + 15%AR-5
Absolute viscosity (cP)	135°C	MB - 827	560.00	923.30	-
	155°C		222.80	388.50	1.702.00
	175°C		-	-	822.50
	177°C		97.30	195.60	750.00
	190°C		-	-	567.50
Absolute viscosity, at 60°C, cP		MB – 827	301,101	-	-
Penetration, 25°C, 100g, 5s, 1/10mm		MB – 107	38.0	77.5	79.0
Softening point, °C, Ring & Ball		MB – 164	54.0	48.2	52.0
Flash point, °C		MB – 50	> 300	> 300	> 300
Specific gravity (kN/m^3)		MB – 387	9.849	10.134	10.193
Index of thermal susceptibility*		-	- 0.9	- 0.6	+ 0.5

* $ITS = \dfrac{500\log PEN + 20SP - 1951}{120 - 50\log PEN + SP}$, where PEN is the penetration (25°C, 100g, 5s, 0,1 mm), and SP is the softening point (°C, Ring & Ball).

Table 4. *Marshall parameters in the optimum binder content.*

Table 4. ***Marshall parameters in the optimum binder content.***

Mix	Optimum binder content (%)	Unit weight (kN/m^3)	Air voids (%)	Voids filled (%)	Stability (kN)	Flow (mm)
M1	5.25	24.348	4.0	78.0	11.04	3.56
M2	5.75	24.290	4.0	77.0	8.83	3.56
M3	6.25	24.093	4.0	79.0	8.83	4.06

Legend: M1: AC40; M2: AC40/12%CRM/10%AR-5; M3: AC40/20%CRM/15% AR-5

Table 5 displays the results obtained in the tests of tensile strength and resilient modulus and Figures 2 and 3 show the comparisons of the results of these tests for the three mixes.

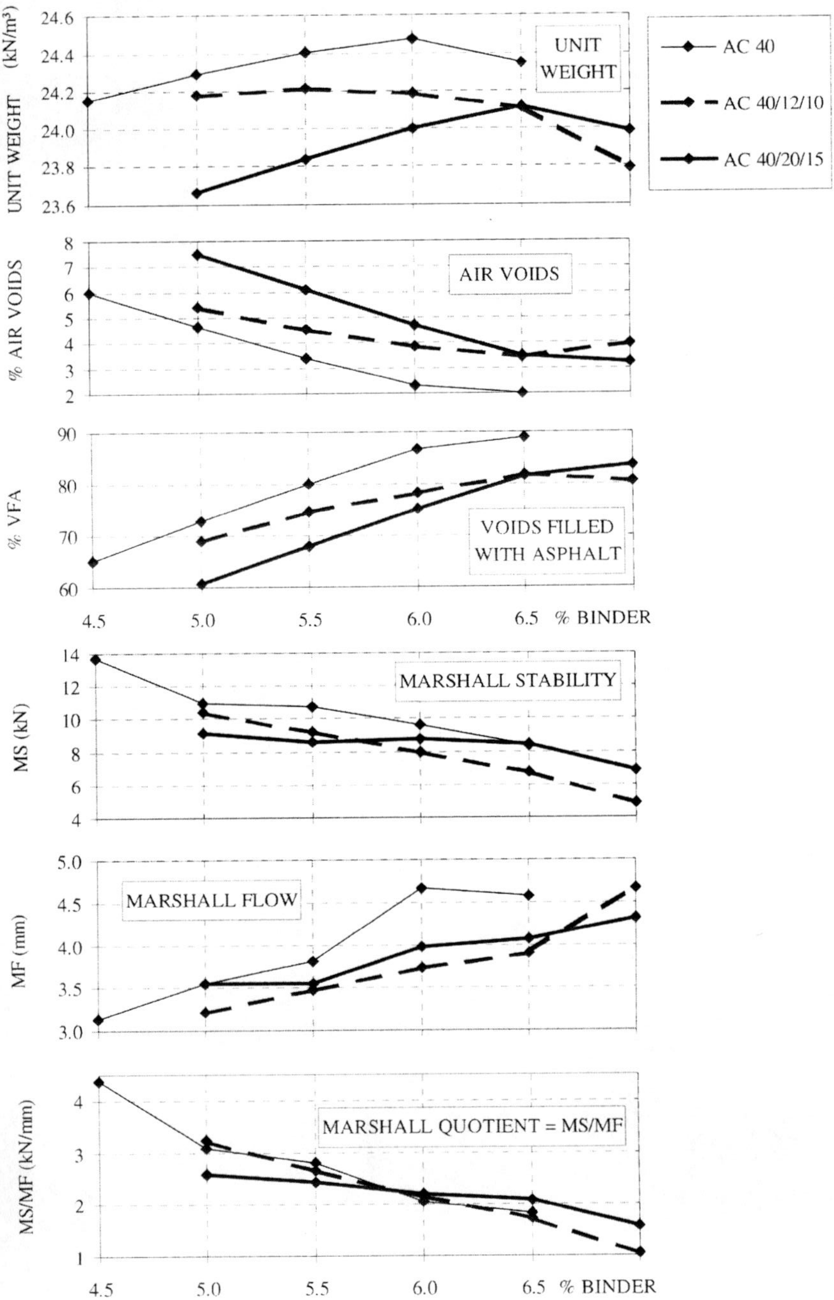

Figure 1. *Comparison of Marshall parameters of the three mixes.*

Table 5. *Results of tensile strength and resilient modulus tests.*

Mix	Tensile strenght			Resilient modulus (MPa)	
	Area (cm²)	Failure load (kN)	Failure stress (MPa)	Stress	M_R
M1	98.73	12.389	1.279	0.300	5,699
M2	99.78	5.050	0.516	0.146	2,514
M3	101.20	5.148	0.519	0.144	1,885

Legend: M1: AC40; M2: AC40/12%CRM/10%AR-5; M3: AC40/20%CRM/15% AR-5

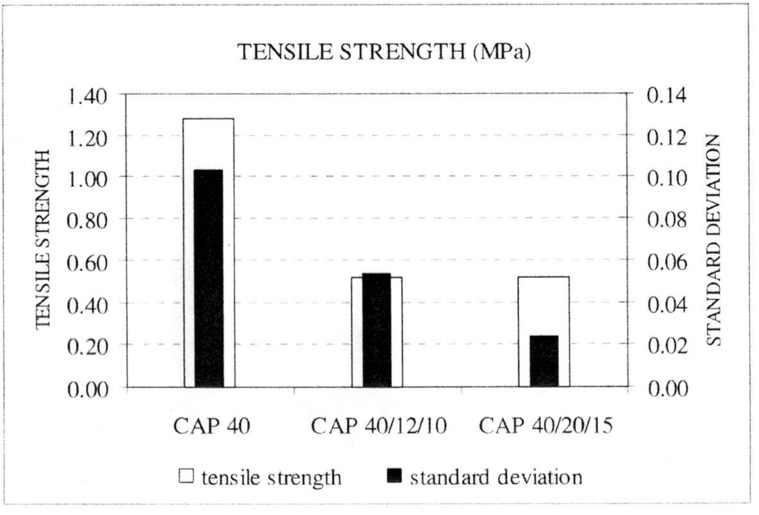

Figure 2. *Comparison of results of tensile strength.*

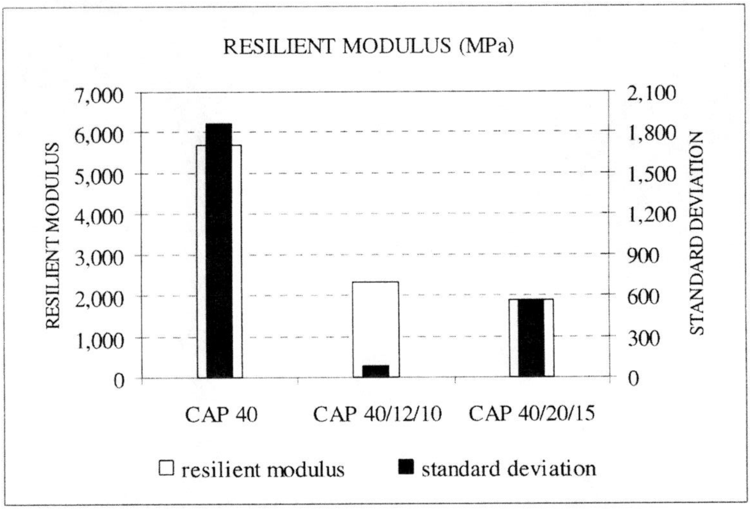

Figure 3. *Comparison of results of resilient modulus.*

Table 6 presents results of total deformation, recoverable deformation, non-recoverable deformation, elastic recovery, creep modulus at the end of the creep test (3,600 s) and at the end of the recovery test (4,500 s) and slope of the steady-state creep curve of the static uniaxial creep test, for 0.4 MPa tension. Table 7 shows the results of these parameters for 0.7 MPa tension.

The total deformation was measured at the end of the load phase of the creep test; the non-recoverable deformation corresponds to the deformation of the specimen at the end of the recovery phase; the recoverable deformation is calculated as the difference between both. The elastic recovery is the ratio between the recoverable deformation and the total deformation and the creep modulus is calculated as the ratio between the applied tension and the total deformation. The slope of the steady-state creep curve is a parameter proposed to characterize the viscous behavior of an asphalt mix in the static creep test [LIT 93]. It indicates the tendency of a mix in accumulating permanent deformation, since it represents the creep rate of the material. The slope was computed in the interval of time between 1,000 and 3,600 s of the creep period.

Table 6. *Average results of parameters of creep test (0.4 MPa).*

Mix	Deformation (%)			Recovery (%)	M_F (MPa)		Creep curve slope
	Total	Recov.	Non-recov.		3,600 s	4,500 s	
M1	0.495	0.280	0.215	56.73	81.09	190.19	0.032
M2	0.432	0.290	0.143	67.23	92.92	291.25	0.016
M3	0.480	0.316	0.164	66.08	83.49	252.27	0.0016

Legend: M1: AC40; M2: AC40/12%CRM/10%AR-5; M3: AC40/20%CRM/15% AR-5

Table 7. *Average results of parameters of creep test (0.7 MPa).*

Mix	Deformation (%)			Recovery (%)	M_F (MPa)		Creep curve slope
	Total	Recov.	Non-recov.		3,600 s	4,500 s	
M1	0.637	0.418	0.216	62.1	109.8	288.06	0.032
M2	0.817	0.440	0.376	54.4	86.24	195.77	0.036
M3	0.725	0.489	0.237	67.7	97.17	309.49	0.042

Legend: M1: AC40; M2: AC40/12%CRM/10%AR-5; M3: AC40/20%CRM/15% AR-5

Table 8 and Table 9 bring the analysis of the results obtained in the creep test for 0.4 and 0.7 MPa, respectively, based on average results and coefficient of variation.

Table 8. *Summary performance of mixes based on creep curve parameters, 0.4 MPa tension.*

Creep curve parameter		Best mixes	Worst mixes	Coefficient of variation (%)
Total deformation		M2[1]	M1	Between 5 and 8
Recoverable deformation		M3[2]	M1	About 5
Non-recov. deformation		M2[3]	M1	Between 17 and 24
Elastic recovery		M2[4]	M1	Between 8 and 9
M_F	3 600 s	M2[5]	M1, M3	Between 5 and 8
	4 500 s	M2[5]	M1	Between 17 and 23
Slope		M2, M3[6]	M1	Very small (M1) and zero (M2, M3)

Legend: M1: AC40; M2: AC40/12%CRM/10%AR-5; M3: AC40/20%CRM/15% AR-5

[1]mix that showed smaller total deformation;

[2]mix that showed larger recoverable deformation;

[3]mix that showed smaller permanent deformation (non-recoverable);

[4]mix that showed larger elastic recovery;

[5]mix that showed smaller total deformation at 3,600 and 4,500s; creep modulus values are calculated as the ratio between the applied tension and the total deformation obtained in the specimen in these two moments;

[6]mix that shows smaller slope, what indicates smaller creep rate.

Table 9. *Summary performance of mixes based on creep curve parameters, 0.7 MPa tension.*

Creep curve parameter		Best mixes	Worst mixes	Coefficient of variation (%)
Total deformation		M1	M2	Between 3 and 10
Recoverable deformation		M3	M1	Between 3.5 and 6.5
Non-recov. deformation		M1	M2	11 (M1) and 24 (M2, M3)
Elastic recovery		M3	M2	14 (M1, M2) and 8 (M3)
M_F	3 600 s	M1	M2	Between 3 and 10
	4 500 s	M3	M2	About 28
Slope		M1	M3	2 (M1), 67 (M2) and 22 (M3)

Legend: M1: AC40; M2: AC40/12%CRM/10%AR-5; M3: AC40/20%CRM/15% AR-5

6. Conclusions

The study showed that the addition of crumb rubber and shale extender oil in the binder for asphalt concrete hot mixes led to satisfactory results in terms of Marshall test parameters. Some differences concerning the Marshall design for conventional binders and modified ones should be emphasized, particularly for mixing and compacting temperatures. The optimum binder content for the modified mixes is larger than the one of the conventional mix, confirming, in some way, the tendency pointed out by the literature, that this increase is equal to the crumb rubber content.

About Marshall parameters, in relation to the conventional mix, the modified mixes show a little decrease of the unit weight values, a significant increase of air voids, and smaller values of Marshall stability. Values obtained for the voids filled with asphalt indicate that it is necessary an increase of binder content so that modified mixes can meet design specifications. Results of Marshall quotient point to superiority of conventional mix (M1: AC 40) and, between modified mixes (M2: AC40/12%CRM/10%AR-5 and M3: AC40/20%CRM/15%AR-5), it is verified a superior performance of mix M2.

With respect to the tensile strength at 25ºC, a significant decrease was verified (larger than 50%) for modified mixes, in comparison to the conventional mix. Decrease was also verified in the resilient modulus, also at 25ºC, of the modified mixes. The resilient modulus of M1 is, approximately, twice as high as the one of M2 and 3 times as high as the one of M3. This indicates, clearly, that the addition of crumb rubber and shale oil makes the mixes more flexible. On the other hand, it is also sensible to consider that AC40 is the hardest available binder in Brazil and that the addition of shale oil would, obviously, cause decrease of binder viscosity.

From the static creep tests it is evidenced, for 0.4 MPa tension, that mix M2 indicated the best performance and M1, the worst. For 0.7 MPa tension mixes M1 and M3 showed the best performance and mix M2, the worst. This leads to the conclusion that, for larger tensions, modified mixes appraised in this study show inferior performance in comparison to conventional mix. However, in a general way, modified mixes show satisfactory rutting performance, evaluated through creep test.

It is believed to be practicable the execution of experimental road segments applying the two modified mixes here studied, once they had satisfactory results for most of the parameters of tests carried out: Marshall stability, Marshall quotient, resilient modulus and static creep test.

The growing concern of government authorities, industries and common citizens with the disposition of solid residues, especially discarded tires, is an incentive for additional researches, either in laboratory or field, about the recycling of tires in asphalt paving services. The initial costs, larger than those observed with conventional binders, can impose obstacles to the large spread of the use of the asphalt-rubber in Brazil. On the other hand, the environmental benefits generated by the recycling of tires, although of difficult quantification, can justify, economically, the choice of asphalt-rubber alternatives. The intensification of studies about discarded tires application in asphalt paving is essential for a sound evaluation of the viability of this technology in the Brazilian highway system. Only based on sound results of laboratory studies and on careful execution and continuous inspections of experimental road segments, accomplished with asphalt-rubber, it will be possible the rational choice of this alternative, that is, a choice that considers the environmental, technological and economical advantages, taking into account the characteristics of available paving materials in the Brazilian territory.

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