COMPARATIVE PERFORMANCE ANALYSIS BETWEEN CONVENTIONAL ASPHALT AND RUBBER-MODIFIED ASPHALT

Rute Coutinho Silva and Bernardo Antonio Silva Ramos
Department of Civil Engineering,
Euro-American University Center, Brasília, Brazil
rute26046@unieuro.com.br
bernardo.ramos@unieuro.edu.br

ABSTRACT

It is expected that road pavements exhibit properties to withstand the mechanical stresses generated by traffic and climatic actions. Rubber-modified asphalt is an alternative to mitigate issues encountered in the conventional asphalt wearing course. The addition of rubber to asphalt mixtures provides an enhancement against the emergence of various pathological manifestations in the surface layer and consequently, in the underlying pavement layers. The utilization of this modified asphalt influences durability, comfort, and maintenance costs of pavements. These aspects are highly relevant given the inadequate maintenance culture in the country. Moreover, there is a reduction in the quantity of discarded tires in nature, minimizing the harmful effects that tires impose on natural resources, the environment, and the population. Based on this context, the objective of this study is to conduct a comparative performance analysis between conventional asphalt and rubber-modified asphalt. Unfortunately, the asphalt-rubber mixtures tested in this study do not outperform conventional asphalt mixtures, and they cannot be used in flexible pavement as a wearing course.

KEYWORDS: *Marshall Test, Conventional Asphalt, Rubber-Modified Asphalt.*

I. INTRODUCTION

The road network holds great importance for the country's development [17]. According to [15], the road model has the highest prominence, covering practically all points of the national territory. Therefore, road pavements must exhibit suitable performance to withstand climatic actions and mechanical stresses generated by traffic.

The pavement is designed for a specific service life, and in Brazil, the projection for flexible surface pavement is around ten years. From the beginning to the end of this service life, the pavement transitions from an optimal condition to a poor condition if no interventions are carried out. The condition of the pavement surface refers to the conservation state of the surfacing and its impact on the comfort and safety of road users. Thus, the condition of the wearing layer's conservation is one of the most perceptible elements for road users, as the irregularities on this surface affect their comfort, traffic rolling safety, and reduce the durability of functional vehicle components [6].

Given Brazil's road-oriented nature, with a federal road network spanning 75.74 thousand km, state, transient, and municipal networks totalling 1.48 million km, and a fleet of 2.76 million trucks [6], there's an urgent need for an improved road system. This system should satisfy not only users and transportation companies but also society as a whole and all sectors of the economy, which depend on it for the country's development. All sectors are affected by authorities' negligence and the lack of pavement maintenance [16].

Rubber-modified asphalt, also known as rubberized asphalt, is an alternative to mitigate issues encountered in the wearing layer of conventional asphalt. In Brazil, the technique of using rubberized asphalt is relatively new, but it has already been adopted in several U.S. states. For example, the Florida Department of Transportation implemented specifications requiring the use of tire rubber in all asphalt mixtures used in asphalt overlays. Since the implementation of these specifications in 1994 until 1999, it is estimated that over 2.7 million tons of rubber-modified asphalt mixtures were used in pavement construction [5].

The rubber content used in asphalt mixtures in Florida (USA) ranges from 5% to 20% by weight added to the mixture [13]. In the state of Arizona, also in the USA, pavement services using rubberized asphalt account for over 90%. In California (USA), rubberized asphalt is used in stress-absorbing membranes, sealing layers, and crack and joint sealants [13]. In Australia, rubberized asphalt is applied as a sealing layer [13].

Rubber-modified asphalt presents improved pavement material properties [16]. The addition of rubber to asphalt mixtures increases flexibility and resistance to ultraviolet rays, making the mixture more resistant to crack initiation and propagation, permanent deformation, and aging. These mixtures provide pavement surfaces with excellent macrotexture, resulting in improved tire-pavement friction. Furthermore, the noise level generated by vehicle traffic is reduced, aiding drainage on rainy days, improving visibility, and reducing aquaplaning risks. It can be said that a rubberized asphalt pavement offers greater comfort, cost savings, and safety for users, along with superior performance and durability compared to a pavement constructed with conventional asphalt [13].

According to [13], this material meets the need for higher quality and greater durability in pavements, which is crucial given that in Brazil, responsible agencies for road infrastructure offer scarce, or even non-existent, pavement maintenance.

For these reasons, the main objective of this study is to evaluate whether rubberized asphalt can be used in the wearing layer pavement, through a comparative analysis between the behaviour of Conventional Asphalt Mixture (CAM) and Rubberized Asphalt Mixture (RAM). This analysis is based on test results obtained and evaluated according to normative parameters, aiming to present an alternative to enhance the quality of traditional pavements.

This article is divided into four sections. The first section serves as an introduction to the topic addressed in the study. The second section describes how the study was conducted, including the materials used, and provides a characterization of all the materials utilized in the study. Additionally, the second section presents the main equations for obtaining the discussed parameters. The third section presents and discusses the primary findings of the study, aiming to describe the observed patterns and, most importantly, to verify if the results align with current technical standards. The fourth section presents the conclusions drawn from the study. At the end of the paper, the bibliographic references that served as the foundation for the study's development are provided.

II. METHODOLOGY

For the development of this research, the company Companhia Urbanizadora da Nova Capital do Brasil - Novacap, provided the materials from their plant as well as their asphalt laboratory for conducting tests and subsequent result analysis.

The methodology employed in this study involved molding cylindrical test specimens of Dense Graded Hot Mix Asphalt (DG-HMA) of both Conventional Asphalt Mixture (CAM) and Rubberized Asphalt Mixture (RAM), followed by testing. This approach allowed for an examination of whether RAM can be used in the wearing layer pavement and, furthermore, whether it outperforms CAM concerning normative parameters specified in [10], which pertains to quality control of asphalt mixtures.

2.1. Real Density of Aggregates

2.1.1. Real Density of Fine Aggregates

The real density of sand and stone powder was determined according to the [7]. This procedure involves placing 200 ml of water in the Chapman flask and subsequently adding 500 g of the corresponding fine aggregate to be tested into the flask. The reading of the water level reached in the flask indicates the volume in cm³ occupied by the water-fine aggregate mixture. The real density of fine aggregates is obtained using the Equation 1.

$$Dr_{Am} = \frac{M_{sample}}{V_{W+FA} - V_{water}} \quad (1)$$

where Dr_{Am} is the real density of fine aggregate in g/cm³, M_{sample} is 500 g of the fine aggregate being tested; V_{W+FA} is the volume reading of the water-fine aggregate mixture in cm³ and V_{water} is 200 cm³ of water. Table 1 illustrates the real densities of fine aggregates.

Table 1. Real Density of Sand and Stone Powder

Fine Aggregate	Volume of the water-fine aggregate mixture (cm³)	Real density (g/cm³)
Sand	391,0	2,618
Stone Powder	384	2,717

2.1.2. Real Density of Coarse Aggregates

The real density of crushed stone 1 and crushed stone 0 was determined according to the [2]. First, the material to be tested was washed to remove any dust or other materials from the surface. After washing the aggregates, they were placed in an oven at a temperature of 105 ± 5 °C for a period of 24 hours to ensure complete drying. After cooling to room temperature, each sample was weighed, and then they were submerged in water for a period of 24 ± 4 hours. After this period, the samples were weighed while submerged in water. The real density of coarse aggregates is obtained using the Equation 2.

$$Dr_{Ag} = \frac{m}{m - m_{sub}} \quad (2)$$

where Dr_{Ag} is the real density of coarse aggregate in g/cm³, m is the dry sample weigh in g and m_{sub} is the submerged sample weight in g. Note the difference between m and m_{sub} is numerically equal to the volume of the aggregate, including permeable voids. Table 2 illustrates the real density of coarse aggregates.

Table 2. Real Density of Coarse Aggregates 0 and 1

Coarse Aggregate	Dry sample (g)	Submerged sample (g)	Real Density (g/cm³)
Coarse Aggregate 1	391,0	2,618	2,766
Coarse Aggregate 2	384	2,717	2,761

2.2. Mixture Characterization

The composition of the Dense Graded Hot Mix Asphalt (DG-HMA) should meet the requirements presented in [10], along with the respective tolerances regarding the granulometry regulated by the [9]. The chosen gradation range for the mixture composition was Range C, as this is the suitable range for composing the wearing course of dense graded DG-HMA.

2.2.1. Conventional Asphalt Mixture

To obtain the gradation curve of the Conventional Asphalt Mixture (CAM), it was necessary to conduct the gradation test of the materials used according to the [9]. These materials included crushed aggregate 1, crushed aggregate 0, stone powder and sand. Table 3 illustrates the composition used for CAM.

Table 3. CAM Composition

Aggregate	Composition (%)
Coarse Aggregate 1	12,0
Coarse Aggregate 2	38,0
Stone Powder	40,0
Sand	10,0%

2.2.2. Rubber-Modified Asphalt Mixture

To obtain the gradation curve of the Rubber-Modified Asphalt Mixture (RAM), the same gradation and materials as those used for CAM were employed, with the added distinction of incorporating ground rubber as a mineral aggregate.

Since there is no specific road test for determining the real density of tire rubber, the value of 1.16 g/cm³ proposed by [4] was adopted, which was obtained using helium pycnometry. Helium pycnometry is a method used to obtain the real density of various materials and is a high-precision test, as helium gas penetrates the sample and fills the voids.

Regarding the rubber content, a content of 1% was chosen to be included in the mixture, following the Generic System methodology, aiming to add ground rubber in replacement of sand or stone powder. Upon conducting the gradation of rubber, the material to be replaced, the presence of polluted material was observed on the 4.8 mm sieve and the larger sieves, including metal fibers, nails, and plastic fragments. Consequently, the decision was made to discard samples from these sieves to avoid compromising the mixture's quality, resulting in samples of smaller particles in the gradation test, ranging from 2 to 0.075 mm. Table 4 present the characterization of the sand and stone powder gradations.

Table 4. Sand and Stone Powder Gradation

Sand Gradation		Stone Powder Gradation	
Sieve Size (mm)	**Percent Passing (%)**	**Sieve Size (mm)**	**Percent Passing (%)**
2,000	99,10	4,800	27,30
0,420	98,40	2,000	74,10
0,180	32,80	0,420	30,40
0,075	5,20	0,180	20,00
		0,075	11,30

Among the materials listed above, the decision was made to replace a portion of the sand with rubber due to this material exhibiting greater visual similarity of grain sizes. Table 5 presents the gradation of the ground rubber.

Table 5. Ground Gradation

Sieve Size (mm)	Percent Passing (%)
2,000	90,30
0,420	42,00
0,180	10,90
0,075	0,80

The percentage of sand before adding rubber to this mixture was 8,0% and became 7,0% due to the replacement of 1,0% of sand with ground rubber. Table 6 illustrates the composition used for RAM.

Table 6. RAM Composition

Aggregate	Composition (%)
Coarse Aggregate 1	10,0
Coarse Aggregate 0	50,0
Stone Powder	32,0
Sand	7,0
Rubber	1,0

2.3. Mixing and Compaction Temperature

2.3.1. Mixing and Compaction Temperature of Conventional Asphalt Mixture

The mixing and compaction temperature of the conventional asphalt mixture can be obtained through the viscosity-temperature graph. Saybolt Furol Viscosity (SSF) is the time in seconds for 60 ml of the sample to flow in a continuous stream through a standardized orifice (Furol orifice) under specified conditions [1].

According to the [8], the mixing temperature of the binder should not be below 107 °C or exceed 177 °C, and its viscosity should be within the range of 75 to 150 SSF, preferably between 75 and 95 SSF. The compaction temperature should be such that the binder exhibits viscosities in the range of 125 to 155 SSF.

Five samples were tested for this assay, following procedure B of the [1], which pertains to bituminous materials with temperatures between 120 °C and 240 °C, and the binder used was CAP 30/45. Table 7 illustrates the obtained results.

Figure 1 illustrates the SSF viscosity of the 5 CAP samples tested as a function of temperature and defines the appropriate mixing and compactation temperatures, wich are 156 to 161°C and 144 to 150 °C respectivelty.

Table 7. Saybolt Furol Viscosity - SSF

Temperature (°C)	121	135	149	163	177
Saybolt-Furol Viscosity (s)	528	215	124	65	42

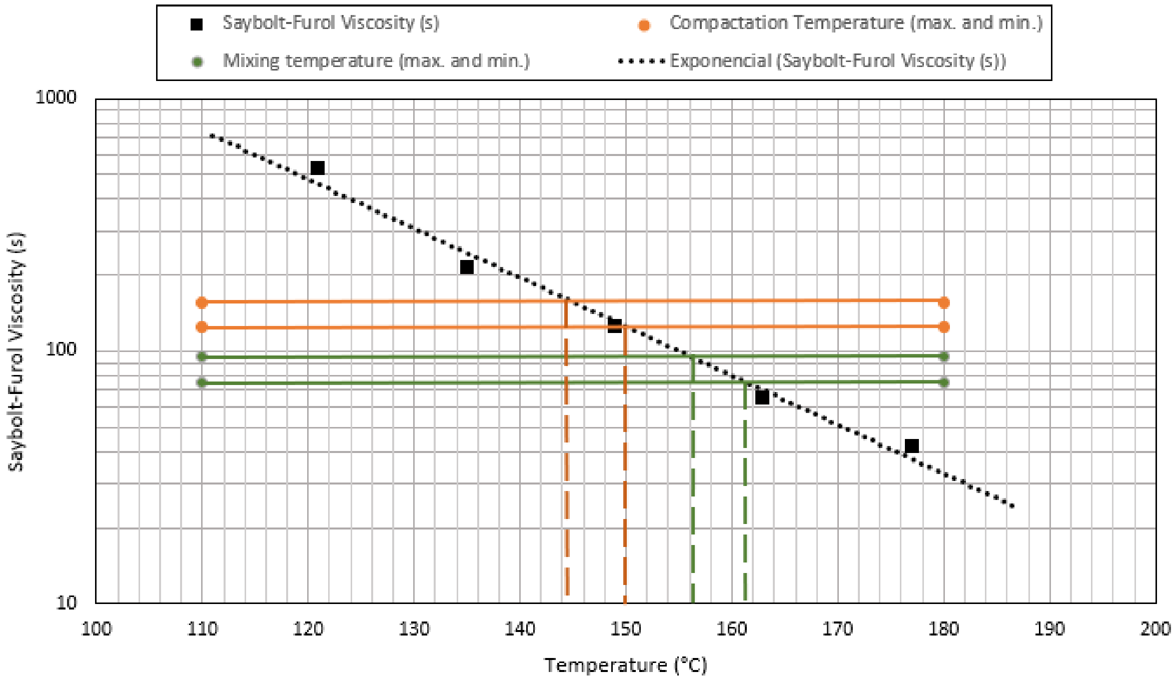


Figure 1. Temperature vs. Saybolt Furol Viscosity (SSF)

2.3.2. Mixing and Compaction Temperature of Rubber-Modified Asphalt Mixture

South Africa has stood out for its successful use of the dry process. The mixing temperature should range from 149 to 177 °C [14]. According to [18], the South African experience recommends preheating the asphalt binder to a temperature ranging from 140 to 160 °C and the aggregate to a temperature of 200 to 210 °C.

The compaction temperature should not be lower than 121°C [12]. Before compaction, the mixture should be stored at 180°C for at least one hour. This period, called digestion, is necessary for interaction between the binder and the granulated rubber and directly influences the performance of the final asphalt mixture [18].

It was not possible to generate a viscosity-temperature graph for RAM due to the absence of normative documents regulating suitable mixing and compaction viscosities. Temperatures are determined based on viscosities, and the mixing temperatures described by [14] would result in a viscosity lower than that specified by the [7].

2.4. Specimen Molding

2.4.1. Bitumen Binder Content Evaluation

The selection of asphalt binder content for the mixtures was based on the contents commonly used in specimens of Dense Graded Hot Mix Asphalt (DG-HMA) tested daily in the Novacap laboratory, ranging from 4.5 to 6.0%.

Three different binder contents were chosen for each gradation composition to observe the behavior of the specimens as the binder content varied and select an ideal content, namely 4.5%, 5.0%, and 5.5%. For each content, 6 specimens were molded: 3 for the Marshall stability test and 3 for the tensile test, totaling 18 specimens for CAM and 18 specimens for RAM.

2.4.2. Bitumen Binder Content Evaluation

The selection of asphalt binder content for the mixtures was based on the contents commonly used in specimens of Dense Graded Hot Mix Asphalt (DG-HMA) tested daily in the Novacap laboratory, ranging from 4.5 to 6.0%.

Three different binder contents were chosen for each gradation composition to observe the behavior of the specimens as the binder content varied and select an ideal content, namely 4.5%, 5.0%, and 5.5%. For each content, 6 specimens were molded: 3 for the Marshall stability test and 3 for the tensile test, totaling 18 specimens for CAM and 18 specimens for RAM.

2.4.3. Mixture Design

Novacap provided the materials from its asphalt plant and asphalt laboratory for the preparation and molding of the specimens. The mixtures were prepared in accordance with the Marshall mix design method, following the [7].

It was possible to adjust the percentage of each material based on the percentage of Asphalt Cement (AC) used for each set of specimens according to the Equation 3 [3]:

$$\%n = \%n^* \times (100\% - \%a) \quad (3)$$

Where %n is the mass percentage of aggregate in the asphalt mixture already containing asphalt cement (AC); %n* is the mass percentage of aggregate in the asphalt mixture without the addition of asphalt cement (AC); and %a is the mass percentage of asphalt binder.

After determining the mass percentage of each material that would compose the mixture, the mass in grams of each aggregate was calculated in order to compose a specimen of 1200 g, using the Equation 4.

$$m = (\%n^* \times (100\% - \%a)) \times 1200 \quad (4)$$

Where m is the mass of aggregate in grams to compose a single specimen (CP).

2.4.4. Preparation of Conventional Asphalt Specimens

After determining the aggregate masses for each binder content, they were weighed and placed in metal trays, properly labeled with tags indicating the Asphalt Cement (AC) content. Consequently, six trays were prepared for each AC content, with three intended for the stability test and three for the tensile strength test. Figure 2 illustrates a tray containing aggregates in the specified quantities in Table 8 to form a conventional asphalt specimen.

The binder was stored in metal cans and left in an oven at a temperature of 150°C for approximately 5 hours before use. Two specimens were prepared at a time with the assistance of a laboratory technician. The aggregates were plaved in mixing containers for heating under controlled flame and were mixed and heated to a temperature of 160 °C, which should be 10 to 15 °C higher than the binder mixing temperature, which is 150 °C. Then, the Asphalt Cement (AC) was carefully added, avoiding direct contact with the container walls to prevent material loss. Mixing continued until all particles were coated with AC, and the aggregate-binder mixture was homogeneous, maintaining the mixing temperature specified in the viscosity test. Figure 3 illustrates the aggregate mixing and heating and the homogenization of aggregates with the binder, respectively.

Figure 2. Aggregate Preparation for Molding

Table 8. Mass of CAM materials

Aggregates	Mass					
	(%)	(g)	(%)	(g)	(%)	(g)
CAP	**4,5**	54,0	**5,0**	60,0	**5,5**	66,0
Coarse Aggregate 1	11,5	137,5	11,4	136,8	11,3	136,1
Coarse Aggregate 0	36,3	435,5	36,1	433,2	35,9	430,9
Stone Powder	38,2	458,4	38,0	456,0	37,8	453,6
Sand	9,6	114,6	9,5	114,0	9,5	113,4

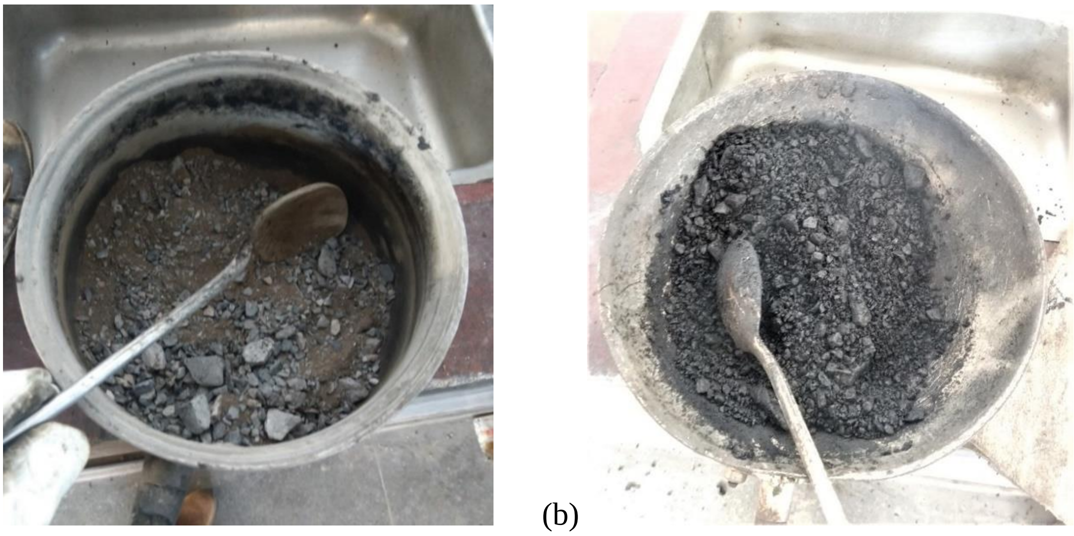
After complete homogeneization and temperature measurement using a thermometer, the mixtures were promptly placed in Marshall compactor molds to ensure compliance with the compaction temperature. Subsequently, 25 blows were applied with a mallet to the center and around the mold to accommodate the mixture. The Marshall compactor was then activated, and 75 blows were delivered to each face of the specimen.

2.4.5. Preparation of Asphalt-Rubber Specimens

The procedure used for the preparation of asphalt-rubber specimens was the same as that used for conventional asphalt specimens, with the exception of mixing and compaction temperatures. Based on the considerations made in section 3.4.2, the aggregates were heated to a temperature of 200 °C, and a mixing temperature of 170 °C was adopted. The compaction temperature was around 10 °C lower than the mixing temperature, similar to the modified asphalt cement (MAC), and it was not possible to carry out the mixture digestion process before compaction due to laboratory limitations.

2.5 Marshall Parameters

After one day, all specimens were demolded for the measurement of Marshall parameters.



(a) (b)

Figure 3. Aggregate Mixing (a); Aggregate-Binder Homogenization (b)

2.5.1 Bulk Density

First, the specimens were weighed in air and then submerged in water to determine the bulk density. The bulk density of a compacted asphalt mixture is determined using the Equation 5 [3].

$$D_{ap} = \frac{m}{m - m_{sub}} \; x \; 0{,}9971 \quad (5)$$

Where D_{ap} bulk density in g/cm³; m is the dry mass of the specimen in g; and m_{sub} mass of the specimen submerged in water in g.

2.5.2 Marshall Stability and Flow

The Marshall stability test was conducted in accordance with the [7]. Three specimens were selected for each asphalt content for both the conventional asphalt mixture and the asphalt-rubber mixture, totaling 9 specimens for each mixture.

The specimens were placed in a water bath with a 1-minute interval between them. After 30 minutes, the first specimen immersed in the water bath was removed and placed in the Marshall press mold for the determination of its stability. This procedure was carried out for all specimens in approximately 1 minute, ensuring that no specimen exceeded the immersion time specified by the standard.

The load in kgf applied to the Marshall press to break a specimen represents the stability reading. This value should be corrected by multiplying it by a factor that depends on the thickness of the tested specimen, as presented in APPENDIX D, and also by the constant of the dynamometer ring, which for the press used is 1.611, according to the laboratory technician. The correction factor is determined by Equation 6.

$$f = 927{,}23 \; x \; h^{-1{,}64} \quad (6)$$

Where f is the correction factor; and h is the thickness of the specimen in mm.

2.5.3. Maximum Theoretical Density (DMT)

The maximum theoretical density of a compacted asphalt mixture is determined by Equation 7 [3].

$$DMT = \frac{100}{\frac{\%a}{Dr_a} + \frac{\%Ag}{Dr_{Ag}} + \frac{\%Am}{Dr_{Am}} + \frac{\%b}{Dr_b}} \quad (7)$$

Where DMT is the maximum theoretical density in g/cm³; %a, %Ag, %Am and %b are the percentages of asphalt, coarse aggregate, fine aggregate, and ground rubber; and Dr_a, Dr_{Ag}, Dr_{Am} and Dr_b are the actual densities of asphalt, coarse aggregate, fine aggregate, and ground rubber.

2.5.4. Voids Volume (Vv)

The percentage of voids in a compacted asphalt mixture is determined by Equation 8 [3].

$$Vv = \frac{DMT - D_{ap}}{DMT} \; x \; 100 \tag{8}$$

Where Vv is the voids volume in %.

2.5.5. Bitumen Voids (VCB)

The percentage of bitumen voids in a compacted asphalt mixture is determined by Equation 9 [3].

$$VCB = \frac{D_{ap} \; x \; \%a}{Dr_a} \tag{9}$$

Where VCB is the bitumen voids in %.

2.5.6. Mineral Aggregate Voids (VAM)

The percentage of mineral aggregate voids in a compacted asphalt mixture is determined by Equation 10 [3].

$$VAM = Vv + VCB \tag{10}$$

Where VAM is the mineral aggregate voids in %.

2.5.7. Bitumen/Voids Ratio (RBV)

The percentage of the bitumen/voids ratio in a compacted asphalt mixture is determined by Equation 11 [3].

$$RBV = \frac{VCB}{VAM} \tag{11}$$

Where RBV is the bitumen/voids ratio in %.

2.6. Tensile Strength

To perform the tensile strength tests, 3 specimens were selected for each asphalt content for both the Modified Asphalt Cement (MAC) and Modified Asphalt Binder (MAB), totaling 9 specimens for each mixture following the procedures regulated by [11]. The tensile strength by diametral compression is determined by the Equation 12.

$$\sigma_R = \frac{2 \; x \; F}{\pi \; x \; D \; x \; h} \tag{12}$$

Where σ_R is the tensile strength in MPa; F is the rupture load in N; D is the diameter of the specimen in mm; and h is the thickness of the specimen in mm.

III. Results and Discussion

3.1. Marshall Parameters

The asphalt mixtures were evaluated and compared based on the results obtained from the Marshall parameters and the tensile strength test, regulated by the [7] and [11], respectively. [10] sets the criteria that must be met for the HMA mixtures to be used in asphalt pavement in the wearing course.

3.2.1 Bulk Density

Using the bulk densities obtained, it was possible to plot a curve of the behavior of the mixtures as the AC content increased, as shown in Figure 4.

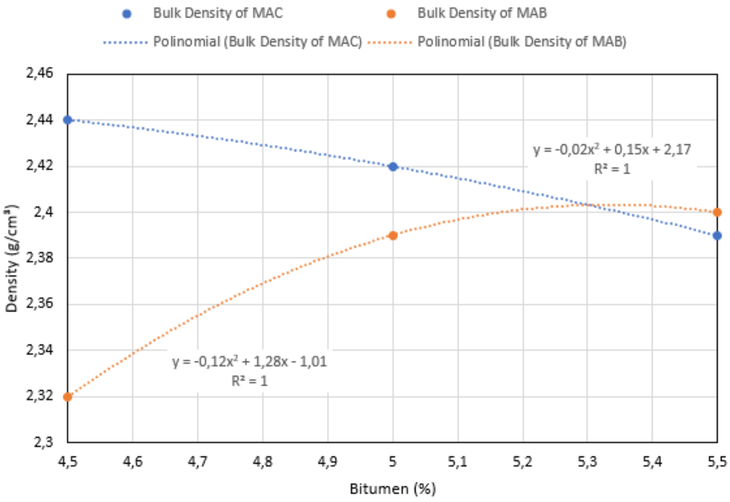


Figure 4. Bulk density of MAC and MAB

According to Figure 4, it can be observed that for MAC, there was a loss of bulk density as the AC content increased. In other words, the mixtures became less dense as the binder content increased. Conversely, for the asphalt mixture with rubber added, there was a gain in bulk density as the AC content increased. This may be related to the expansion of the mixture when ground rubber is incorporated at high temperatures.

3.2.2. Stability

Using the stability values obtained, it was possible to plot a curve of the behavior of the mixtures as the AC content increased, as shown in Figure 5.

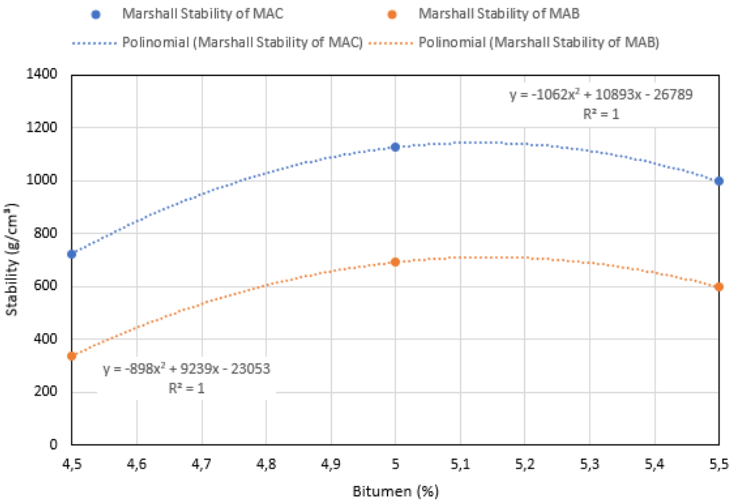


Figure 5. Stability of MAC and MAB

According to Figure 5, all CPs of MAC had stability values higher than the minimum required by the standard, which is 500 kgf [10]. The 5.0% AC content showed the best stability behavior. In contrast, MAB exhibited lower stability values, with the 5.0% AC content performing the best and the 4.5% AC content failing to reach the minimum stability requirement.

For the conventional asphalt mixture, there was an increase in flow when the AC content decreased, indicating a higher susceptibility to deformation for lower AC content. For subsequent AC contents, the flow remained relatively constant. The asphalt-rubber mixture showed a discontinuous but similar flow behavior. There was more flow for the 4.5% AC content and less flow for the 5.0% AC content. Thus, the asphalt-rubber mixture exhibited better flow behavior, with lower deformation values.

3.2.3. Maximum Theoretical Density

Using the maximum theoretical densities obtained, it was possible to plot a curve of the behavior of the mixtures as the AC content increased, as shown in Figure 6.

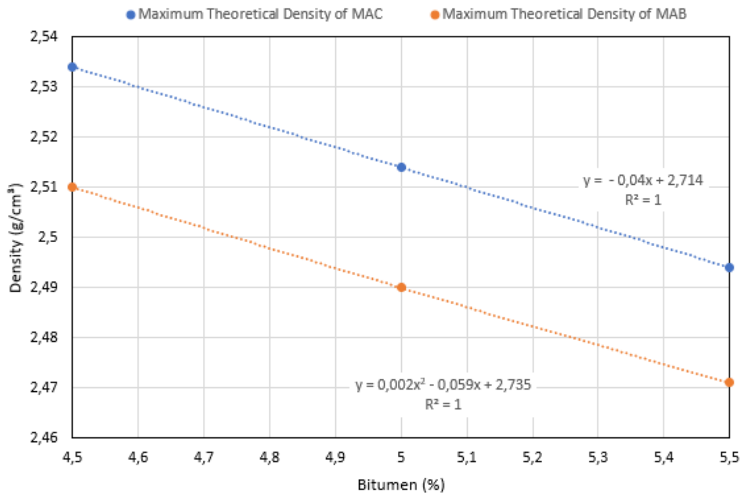


Figure 6. Maximum Theoretical Density of MAC and MAB

According to the tables above, both the conventional asphalt mixture and the asphalt-rubber mixture experienced a loss of maximum density as the AC content increased.

3.2.4. Voids Volume

From the results obtained, graphs illustrating the behavior of the mixture in terms of voids volume as the AC content increased, as shown on Figure 7.

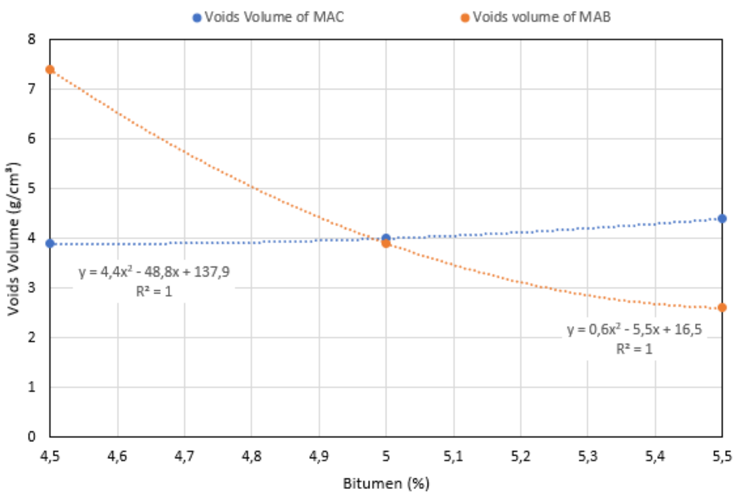


Figure 7. Voids Volume of MAC and MAB

It can be observed that for the conventional asphalt mixture, there was a gradual increase in the percentage of voids as the AC content increased. In contrast, the asphalt-rubber mixture showed a decrease in the percentage of voids as the AC content increased. It can also be noted that both the 4.5% and 5.5% AC content asphalt-rubber mixtures do not meet the requirements of [10], which stipulates that the voids percentage should range from 3% to 5% for the mixture to be used in the wearing course.

3.2.5. Mineral Aggregate Voids

From the results obtained, Figure 8 illustrates the behavior of the mixture in terms of mineral aggregate voids as the AC content increased.

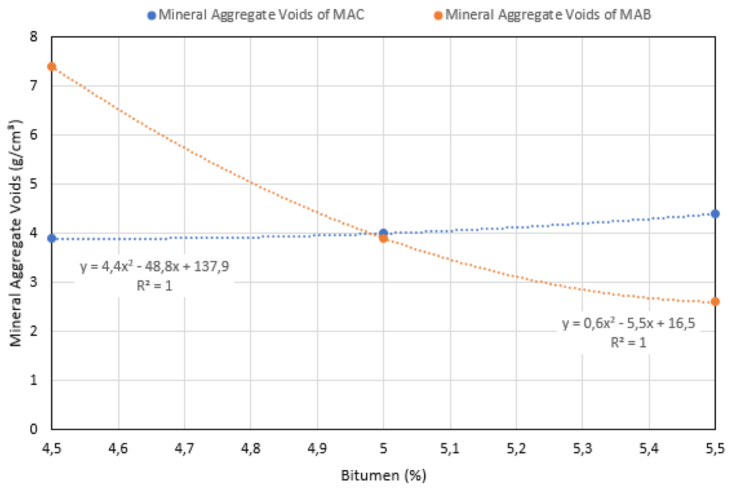


Figure 8. Mineral aggregate voids of MAC and MAB

Regarding the percentage of mineral aggregate volume, there was a continuous increase for the conventional asphalt mixture as the AC content increased. However, for the asphalt-rubber mixture, there was a decrease in this factor as the AC content increased, with the 5.0% and 5.5% AC content mixtures being relatively constant. It can also be noted that the conventional asphalt mixture with 4.5% AC content, as well as the asphalt-rubber mixtures with 5.0% and 5.5% AC content, do not meet the requirements of [10] because the percentage of mineral aggregate volume should be at least 16, considering that the nominal maximum aggregate size of the mixtures in question is 12.7 mm.

3.2.6. Bitumen/Voids Ration

From the results obtained, Figure 9 illustrates the behavior of the mixture in terms of the bitumen/voids ratio as the AC content increased.

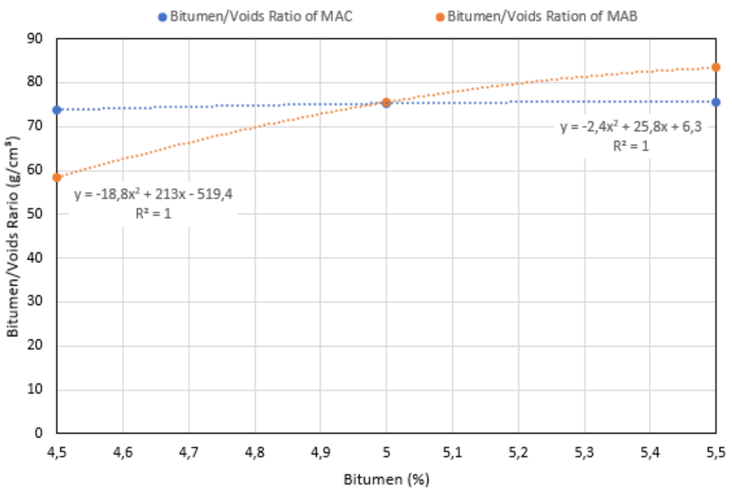


Figure 9. Bitumen/Voids Ration of MAC and MAB.

Regarding the bitumen/voids ratio, there was a slight gradual increase for the conventional asphalt mixture as the AC content increased. In contrast, for the asphalt-rubber mixture, there was a considerable gradual increase as the AC content increased. It can be observed that the conventional asphalt mixture with 4.5% AC content and the asphalt-rubber mixtures with 4.5% and 5.5% AC content do not meet the requirements of [10], as the bitumen/voids ratio percentage should range from 75% to 82% for use in the wearing course.

3.2.7. Tensile Strength

From the results obtained, Figure 10 illustrates the behavior of the mixture in terms of tensile strength as the AC content increased.

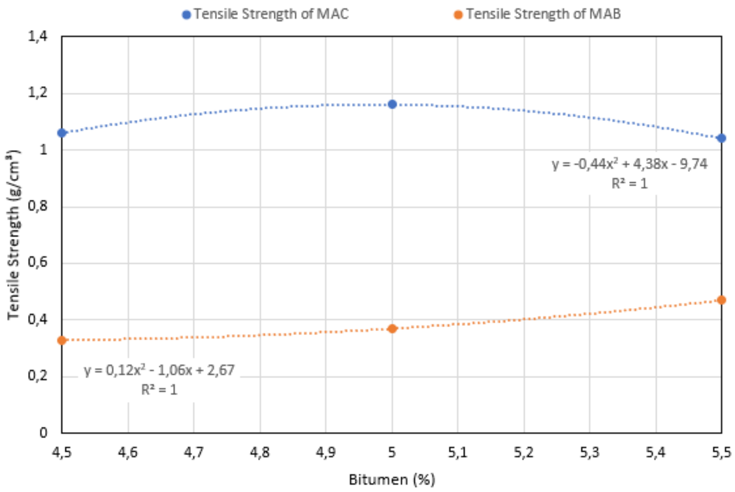


Figure 10. Tensile Strength of MAC (a) and MAB (b)

Regarding tensile strength, it was observed that for the conventional asphalt mixture, the highest gain in strength was at the 5.0% AC content. Subsequently, there was a loss of strength at the 5.5% AC content, even lower than the 4.5% AC content. Therefore, a higher asphalt content resulted in lower strength. On the other hand, the asphalt-rubber mixtures showed a gradual increase in strength as the AC content increased. However, none of the mixtures met the required strength according to the standard. Consequently, these mixtures cannot be used in pavement as a wearing course.

IV. CONCLUSION

Based on the tests conducted and the results obtained for this research, several conclusions can be drawn.

Regarding conventional asphalt mixtures, only one did not meet the regulatory parameters of [10], which is the 4.5% AC content mixture. The other mixtures met the regulatory parameters, and it can be stated that the 5.0% AC content mixture is the most suitable for use in flexible pavement as a wearing course. It exhibited better stability and tensile strength behavior, as well as a lower void volume.

As for the asphalt mixtures with rubber added, none of them met the regulatory parameters of [10], as none of them achieved the required tensile strength, which should be a minimum of 0.65 MPa for the wearing course. However, the mixture with 5.0% AC content showed the best behavior, similar to the conventional asphalt mixture, as it exhibited higher tensile strength and was the only one that met the requirements for void volume (%) and bitumen/voids ratio (%).

Therefore, it can be concluded that the asphalt-rubber mixtures tested in this study do not outperform conventional asphalt mixtures, and they cannot be used in flexible pavement as a wearing course. Even if the asphalt-rubber mixture with 5.0% AC content had achieved the minimum tensile strength, the conventional asphalt mixture with 5.0% AC content would still have had an increase of 78.46% in tensile strength and 62.72% in stability compared to the tested asphalt-rubber mixture. This makes it technically unfeasible.

Further study is warranted to determine if the 5.0% AC content mixture can be used in another capacity in pavement construction, such as surface treatments, especially for crack sealing treatments that involve the use of seal coats, asphalt slurry seals, and microsurfacing.

ACKNOWLEDGEMENTS

The authors would like to thank NOVACAP for providing the asphalt laboratory and a technician who made this study possible.

REFERENCES

[1]. ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 14950: Materiais betuminosos - Determinação da viscosidade Saybolt Furol. Rio de Janeiro, 2003.

[2]. ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR NM 53: Agregado graúdo – Determinação da densidade e da absorção de água. Rio de Janeiro, 2009.

[3]. BERNUCCI, L. B., MOTTA, L. M. G., CERATTI, J. A. P., SOARES, J. B. Pavimentação asfáltica: formação básica para engenheiros. 3ª. Reimpressão. PETROBRÁS - Petróleo Brasileiro S/A / ABEDA - Associação Brasileira das Empresas Distribuidoras de Asfalto. Rio de Janeiro. 2010.

[4]. BERTOLLO, S. A. M. Avaliação laboratorial de misturas asfálticas densas modificadas com borracha reciclada de pneus. Tese (Doutorado). Universidade de São Paulo, Escola de Engenharia de São Carlos, São Carlos, 2002, 198 p.

[5]. CHOUBANE, B.; SHOLAR, G. A.; MUSSELMAN, J. A.; PAGE, G. C. Ten-year performance evaluation of asphalt-rubber surface mixes. TRR 1681, TRB, 1999. p.10-18.

[6]. CNT – Confederação Nacional dos Transportes. Boletim Estatístico, 2018.

[7]. DNER - DEPARTAMENTO NACIONAL DE ESTRADAS DE RODAGEM. DNER-ME 043/95: Misturas betuminosas a quente – ensaio Marshall. 1995.

[8]. DNER - DEPARTAMENTO NACIONAL DE ESTRADAS DE RODAGEM. DNER-ME 083/98: Agregados – análise granulométrica. 1998.

[9]. DNER - DEPARTAMENTO NACIONAL DE ESTRADAS DE RODAGEM. DNER-ME 194/08. Agregados – determinação da massa específica de agregado miúdo por meio do frasco Chapman. 1998.

[10]. DNIT - DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES. DNIT 031/2006 – ES: Pavimentos flexíveis – Concreto asfáltico – Especificação de serviço. 2006.

[11]. DNIT - DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES. DNIT 136/2018 – ME: Pavimentação asfáltica – Misturas asfálticas – Determinação da resistência à tração por compressão diametral – Método de ensaio. 2018.

[12]. EPPS, Jon A. Use of Recycled Rubber Tires in Highways. NCHRP Synthesis of Highway Practice n° 198. Washington: Transportation Research Board, 1994. 17- p.

[13]. JÚNIOR, J. L. F.; EDEL, G.; ODA, S. Primeiro trecho experimental urbano de SMA com asfalto-borracha sem fibras: projeto, construção e avaliação. Revista Minerva - Pesquisa & Tecnologia, São Paulo, v. 2, n. 2, jul./dez. 2005, 203-2016 p.

[14]. KLINSKY, L. M.G. FARIA, V. C. Asfalto Borracha: Revisão bibliográfica, avaliação reológica do ligante asfáltico e determinação dos parâmetros mecânicos das misturas asfálticas. 2007. 147 p.

[15]. RAMALHO, A. V. F. Uma análise dos benefícios com a utilização do asfalto borracha nas Rodovias do Brasil. Faculdade de Tecnologia da Zona Leste, São Paulo, 2009, 77 p.

[16]. SANCHES, F. G.; GRANDINI, F. H. B. e JUNIOR, O. B. Avaliação da viabilidade financeira de projetos com utilização do asfalto-borracha em relação ao asfalto convencional. Universidade Tecnológica Federal Do Paraná, Departamento Acadêmico de Construção Civil, Curitiba, 2012, 73 p.

[17]. SILVA, C. E. D. B. D. Estudo da permeabilidade de misturas asfálticas de graduação aberta. Universidade Estadual de Campinas. Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Campinas, 2005, 130 p.

[18]. SPECHT, L. P. Avaliação de misturas asfálticas com incorporação de borracha reciclada de pneus. Tese (Doutorado). Universidade Federal do Rio Grande do Sul, Porto alegre, 2004, 279 P.