BENEFITS OF INCORPORATING TIRE RUBBER INTO ASPHALT BINDER FOR RUBBERIZED ASPHALT

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ABSTRACT

When designing an asphalt overlay, it is essential to ensure that, in addition to providing comfort and safety to traffic, it also protects the sub-base, base, reinforcement, and subgrade layers. To achieve this, it is important to analyze the characteristics of the materials used and their behavior within the pavement structure. This study aims to analyze the results obtained in laboratory tests of asphalt binder with the use of ground tire rubber as an addition to asphalt cement through the wet incorporation process. The objective is to determine and evaluate the influence of the addition at different levels and compare them to conventional asphalt binder without any addition. The necessary data for the study and the main characteristics of the binder were obtained in the laboratory through tests such as penetration, softening point, flash point, elastic recovery using a ductilometer, and Saybolt-Furol viscosity. Analyzing the results obtained, it is evident that there are benefits to adding tire rubber to the physical behavior of the binder. It was possible to determine that there was an increase in the material's melting point compared to the binder without any addition, indicating an increase in resistance to permanent deformations. It was also observed that there is an increase in the consistency and ductility of the material with increasing rubber content, contributing to increased shear resistance and elasticity modulus, which could help reduce the occurrence of cracks in the pavement surface.

KEYWORDS: *Pavement, Asphalt Binder, Rubberizes Asphalt & laboratory Tests.*

I. INTRODUCTION

Road transportation is considered the primary mode of transportation in the country, given its significance in the cargo transportation matrix and extensive territorial coverage. Data from the Road Research [10] indicate that over 60% of cargo transportation and more than 90% of passenger trips in Brazil are carried out on highways, making it essential to make substantial investments in transportation infrastructure to ensure safety.

Pavement is a structure consisting of multiple layers of finite thickness, designed to simultaneously resist and distribute the vertical forces produced by traffic to the subgrade, thus making the road surface more durable and improving ride quality and safety [15].

Pavement classification is typically divided into two basic types: rigid and flexible. Generally, literature presents rigid pavements as those consisting of Portland cement in their surface layer, while flexible pavements, also referred to as asphalt pavements, are those where the surface layer is primarily composed of aggregates and asphalt binders [8].

However, there is controversy regarding this classification, as some authors like [15] consider the overall functional behavior of the pavement for classification, regardless of the material used in the surface layer.

According to the Road Research [10], in the Federal District, capital of Brazil, none of the evaluated highways are in poor condition, 15.4% are in a bad state, and 32.2% are rated as regular. In response to the challenges faced by the country regarding the quality of Brazilian highways, which exhibit various forms of degradation and pathologies, the application of modified binders to the pavement can alter its characteristics, thereby extending the durability of the surface.

There are studies related to the use of alternative materials in pavement construction, with a particular focus on the incorporation of tire rubber into asphalt binders. These studies aim to find ways to mitigate damage, such as permanent deformation, fatigue cracking, the effects of exposure to high or low temperatures, and oxidative aging, ensuring the functionality of highways throughout their design life [13].

To extend the pavement's lifespan, one solution is the incorporation of ground rubber into asphalt cement, thus creating a binder from recycled tires. The environmental advantage of providing proper disposal for unusable tires and the technical improvement that asphalt binders gain through rubber modification are the main drivers for the use of this type of binder [14].

[9] discusses the two methods for incorporating tires into asphalt mixes. The first method is the dry process, where rubber particles replace some of the aggregates in the mix. After the addition of the binder, a product known as asphalt concrete modified with rubber addition is formed. The second method, which is the focus of this study, is called the wet process, where fine rubber particles are added to the asphalt cement, producing a new type of binder called asphalt-rubber.

Thus, this article aims to comparatively analyze the behavior of asphalt binders with ground rubber added using the wet process addition method versus conventional binders without any addition.

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 the tests performed to characterize the asphalt binders modified with rubber. The third section presents and discusses the primary results of the study with the aim of describing the observed patterns and, most importantly, verifying 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

This study aims to compare samples of conventional asphalt binder and modified binder with the addition of ground recycled tire rubber at three different percentages: 4%, 8%, and 16%. These percentages were empirically chosen based on the studies conducted by [13]. The laboratory testing was conducted at the Asphalt Laboratory of the Department of Highways and Roads of Federal District (DER-DF). To assess and analyze the asphalt binder regarding its cohesion, consistency, and elasticity properties, the following tests were performed: Penetration, Softening Point, Flash Point, Elastic Recovery, and Saybolt-Furol Viscosity. The obtained results were analyzed and compared to the binder without any addition.

2.1 Materials used.

For this study, two materials were used: petroleum asphalt cement and rubber. The study utilized shreds of ground rubber obtained from non-serviceable tires, which were provided by the company DFL Distribuidora de Pneus JC located in Brasília, Federal District. Initially, the rubber underwent a separation process of the tire's constituent materials conducted by the company itself, which involved removing the metallic reinforcement and using only the rubber, which was ground into various sizes. The obtained rubber then underwent a process to remove impurities (small metal particles and organic matter) that had been ground together with the rubber. This process was carried out through sieving and manual separation by the authors of this study.

Figure 1 depicts the impurities present in the ground rubber from shredded tires, as well as the rubber used.

Figure 1. Ground rubber used (left) and Impurities (right).

The particle size range used encompasses material that passes through ASTM sieve number #50 (0.300mm) and is retained by sieve number #60 (0.250mm). The selected particle size range was determined through experiments related to the material's ease of dissolution with the asphalt cement (CAP), and the chosen interval provided the best workability. The particle size distribution curve of the material used is represented in Figure 2.

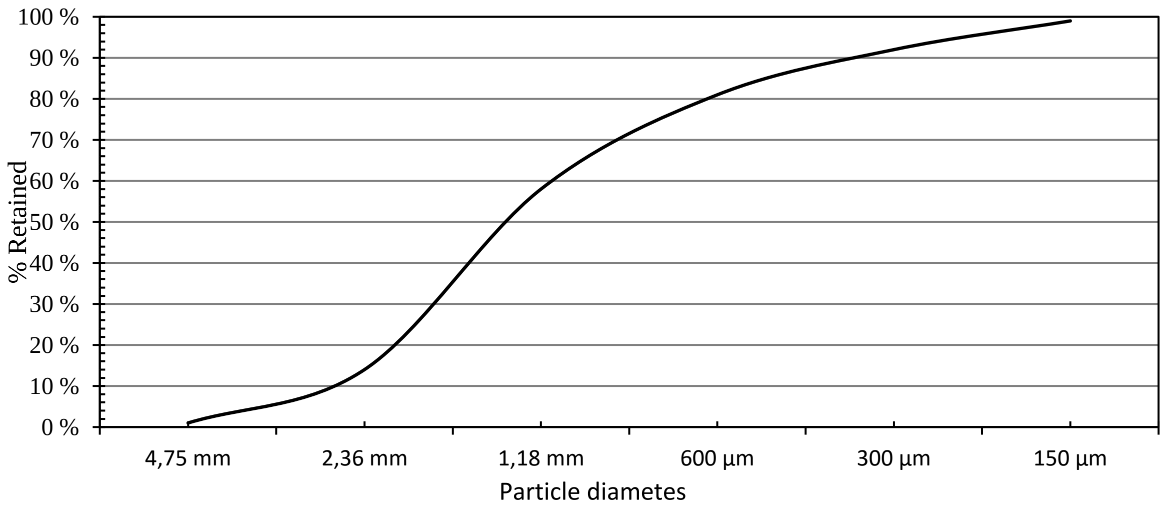

Figure 2. Granulometric curve of rubber

The particle size and percentages were chosen empirically to provide better mixing conditions of the rubber with the CAP and were based on the studies conducted by [13].

The CAP used had a classification of 30/45 in terms of penetration and was provided by the company Prepav S.A. Its characteristics and specifications are described in the [6].

2.2 Sample Preparation

The CAP samples were divided into two groups: one without any addition and another with the addition of rubber. Subsequently, these samples were mixed in the laboratory of the Roadway Yard of DER-DF. The samples without the addition of rubber were stored in an aluminum container in an oven at temperatures between 105°C and 110°C. For the molding of the specimens, no special heating measures for the CAP were required. The CAP only needed to be at the temperature required for each type of test, as described in the standards presented in this study. The heating was accomplished using an aluminum container heated by a Bunsen burner.

For the rubber and CAP mixture, three different rubber percentages were used: 4%, 8%, and 16% by weight in relation to the CAP sample. The mixture was prepared in an aluminum container heated by a Bunsen burner. The CAP was mixed with rubber at a temperature of approximately 105°C and stirred with a metal spatula at a temperature ranging from 175°C to 180°C for a period of 5 to 10 minutes, depending on how well the rubber dissolved in the binder.

The mixture was continued until the rubber lost its granular appearance and had a liquid-like consistency. A thermometer was used during the mixing process to ensure that there was not a significant temperature variation, as the temperature was chosen to prevent premature aging of the rubber due to high temperatures.

After mixing, the CAP with the rubber addition was also stored in an aluminum container in an oven with temperatures ranging from 105°C to 110°C in the DER-DF laboratory, which falls within the specified limit as indicated in [1]. This technical bulletin indicates a storage temperature of 180°C for Rubber Modified Asphalt (RMA).

Figure 3 below illustrates the process used to mix rubber with the CAP.

Figure 3. Incorporation of rubber into CAP.

2.3 Tests

2.3.1 Softening Point

The Softening Point test, also known as the Ring and Ball test, is governed by [4] and aims to determine the temperature at which the material exhibits characteristics close to the melting point. It can be considered an empirical measure for determining this property.

As depicted in Figure 4, the testing method essentially involves shaping the material into standardized ring-shaped specimens, which are then cooled to room temperature. Standardized metal balls are added to the specimen in a container filled with water, and the temperature is increased at a constant rate, causing the sample to soften due to the weight of the balls. The softening point corresponds to the average of three temperatures at the moment the ball touches the reference plate.

Figure 4 below shows one of the test specimens used, as well as the measuring apparatus.

Figure 4. Test specimen (left) and apparatus (right) for the Softening Point test.

2.3.2 Penetration

The Penetration test is standardized by [5], and its goal is to determine the consistency of the material. This property is widely used as a parameter for classifying the CAP. The experimental procedures for conducting the test include melting the material, filling the specific container for the test, cooling the material to room temperature, and submerging it in a water bath under controlled temperature conditions. After the prescribed time, penetration is performed using a standardized needle in an apparatus called a penetrometer.

Figure 5 below shows the mold and the results of the 8% mixture used in the study.

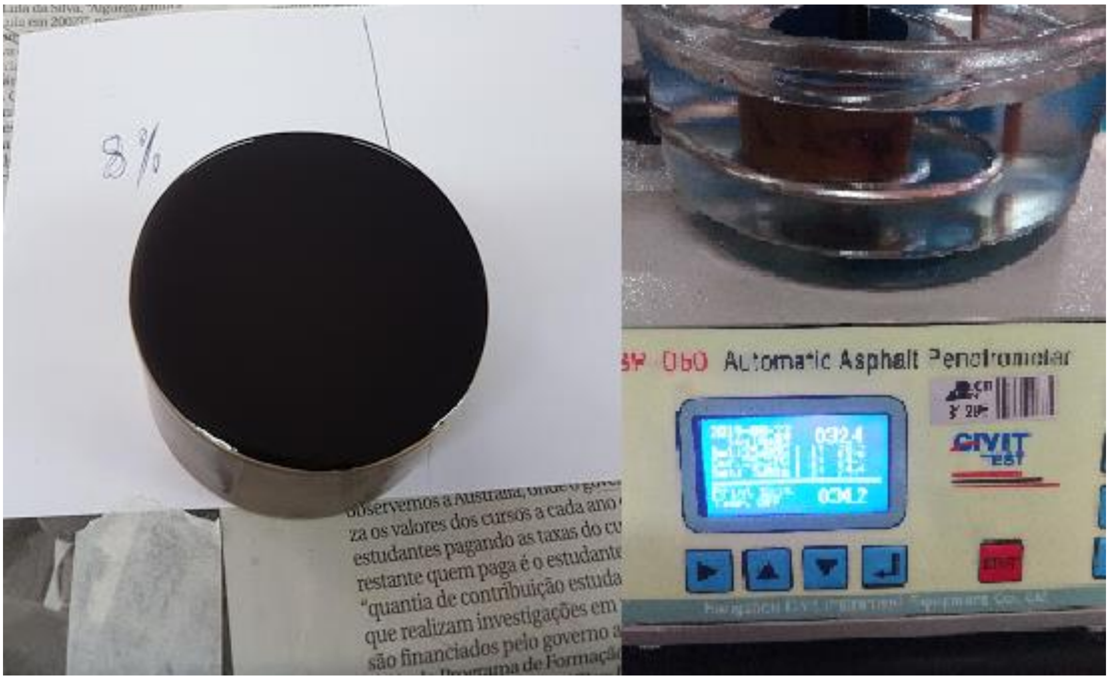

Figure 5. Mold for the Penetration test (left) and its respective results (right).

According to [5], the penetration value corresponds to the distance in tenths of millimeters that the needle penetrates vertically into the standardized container under previously established conditions of load, time, and temperature.

2.3.3 Flash Point

This test is standardized by [2] and aims to measure the temperature at which the material emits sufficient gases and vapors to create a flammable mixture. According to the [2] standard, the flash point value is the lowest temperature corrected to the barometric pressure of 101.3 kPa at which applying a flame to the surface of the sample causes ignition and flame propagation that instantly extinguishes after its application.

The method involves adding an approximate amount of 70 ml of the sample to the test container, which is initially heated quickly and steadily and then more slowly over time. A test flame is passed over the surface of the container at specified intervals to determine if flame propagation occurs.

Figure 6 shows the moment when the DER team passes the flame over a portion of the binder to check for the release of flammable gases.

Figure 6. Checking for the release of flammable gases.

2.3.4 Elastic Recovery

The measurement of elastic recovery aims to verify the ductility of the material and can be measured through the Elastic Recovery test standardized by the [12].

The test involves molding a specimen in a standardized container, as depicted in Figure 7. After the molding steps, the specimen is removed from the container and placed in the ductilometer, submerged in a bath under predetermined conditions. Once the mold and bath preparation conditions are met, as well as fitting into the apparatus, traction at a standardized constant speed is initiated until a length of 20 cm is reached, as observed in Figure 7. After elongation of the material, it is cut in half, and the portion that returns to its original state is measured.

The test result is expressed as a percentage and is defined as the average of the results of three tests molded with the same material sample. The values of speed and temperature adopted for the test should be reported.

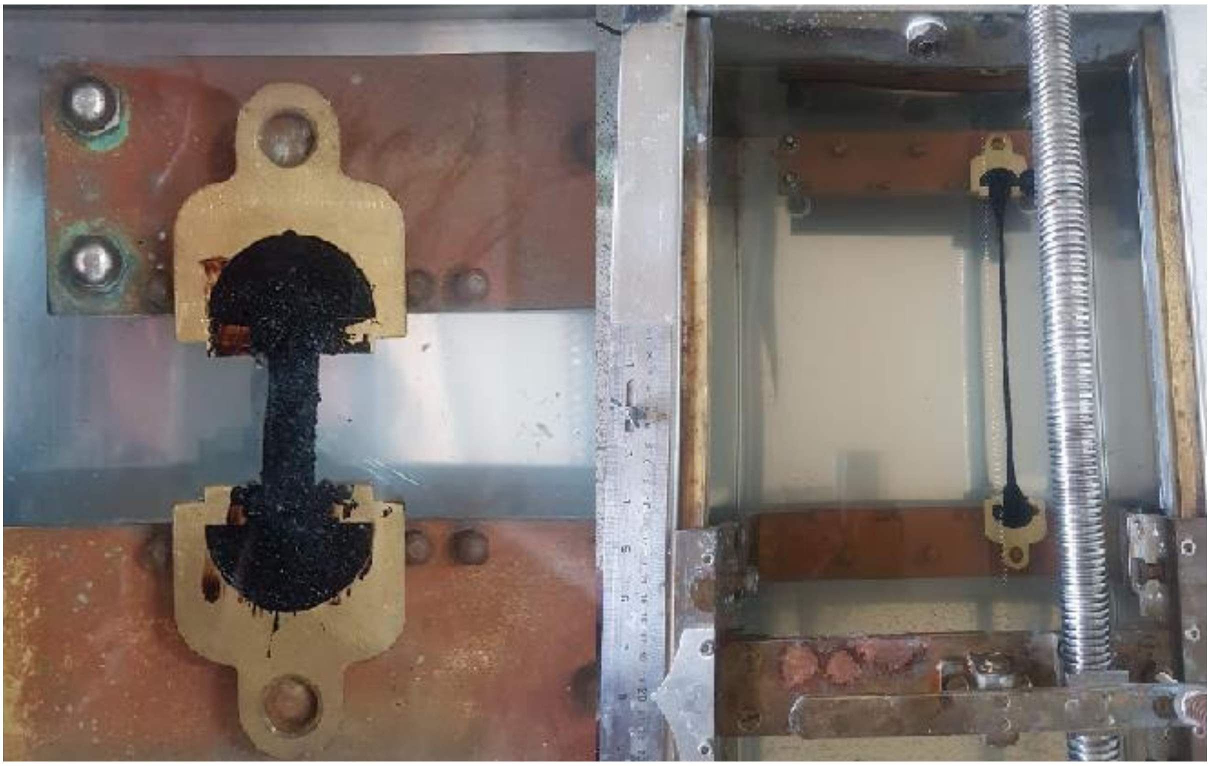

Figure 7. Mold (left) and specimen elongation (right) for the Elastic Recovery test.

2.3.5 Saybolt-Furol Viscosity

The viscosity test is standardized by [3] and aims to determine the time it takes for the sample to flow at a specific temperature. The test involves, in summary, heating the sample to temperatures slightly higher (10°C to 15°C) than the test temperatures while continuously homogenizing it to prevent overheating of the mixture. This homogenization should be done within 2 hours, and reheating the sample is not allowed.

After preparing the material as specified in the standard, the sample is poured into the tube of the Furol equipment, and the outlet orifice of the equipment is sealed until the sample reaches the test temperature steadily over a specified time interval. Then, the material is released to flow, and the time required for the complete flow of the sample is timed. The result is expressed as the measured time corrected by the value of the viscometer used.

Figure 8 below shows the apparatus used for the Saybolt-Furol Viscosity test.

Figure 8. Saybolt-Furol viscometer used.

III. RESULTS

3.1 Softening Point

As shown in Figure 9, the test yielded expected results, where there was an increase in the softening point with the addition of rubber to the binder. This increase is in line with the findings of [13], indicating an improvement in resistance to permanent deformations. The test relates the temperature obtained to the melting point of the materials, which was higher for rubber compared to conventional CAP, thus leading to the observed increase.

It is also noticeable that for a 4% rubber addition sample, the result was lower than expected, meaning it was lower than the value of the sample without any addition. This suggests a decrease in the softening point of the material. This result is believed to be due to the low amount of rubber, which reduces the amount of CAP in the mixture while not being sufficient to increase the softening point.

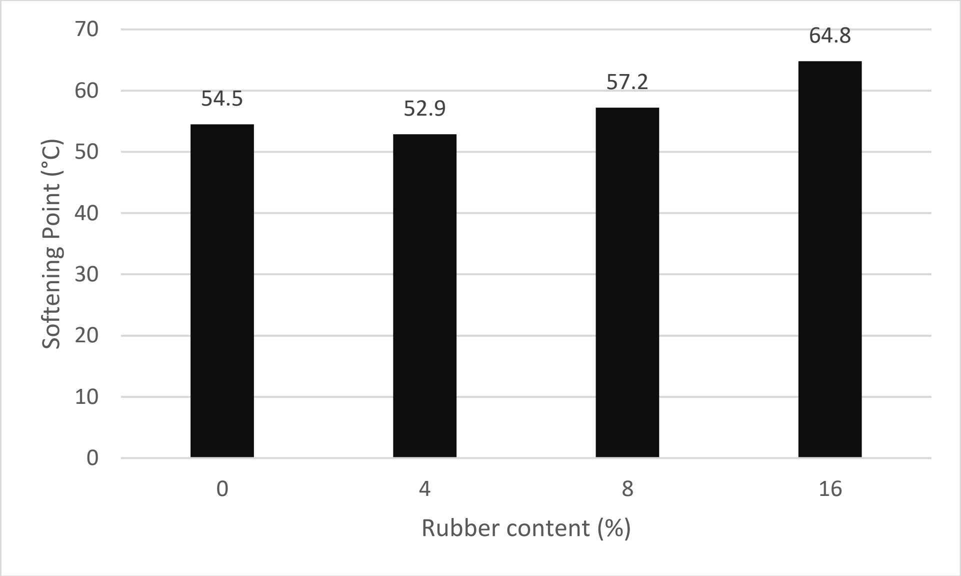

Figure 9. Softening Point.

3.2 Penetration

The results obtained are presented in Figure 10 and showed increasing penetration values with lower rubber contents, represented by 4% and 8%, and lower values for rubber content starting from 16%. These results align with expectations, as confirmed by [13]. They observed that for rubber contents above 12%, there is a decrease in the viscosity of the material, which is believed to be due to the high amount of elastomers present in rubber.

Lower penetration values indicate an increase in consistency, implying an increase in shear resistance and modulus of elasticity of the binder [18].

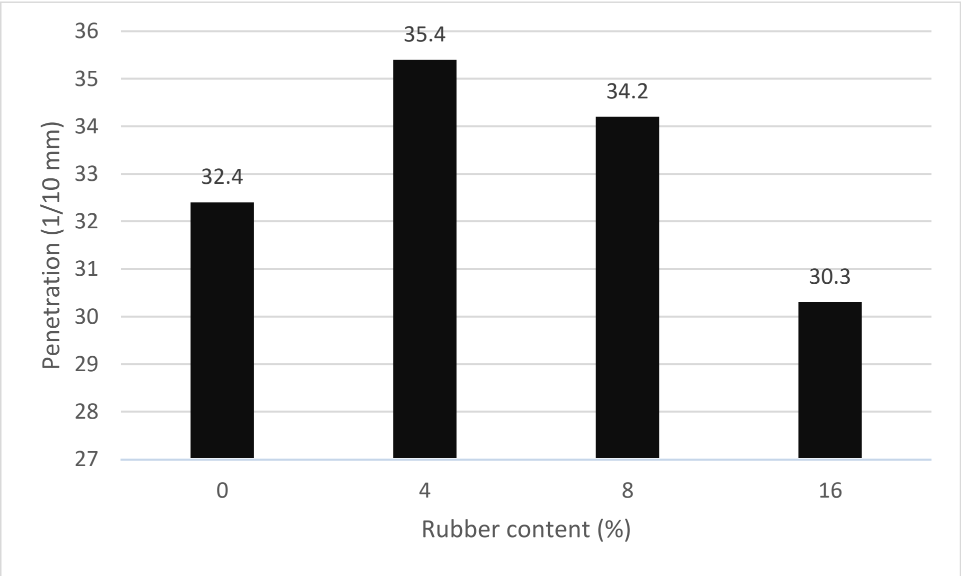

Figure 10. Penetration.

3.3 Flash Point

The obtained flash point values of the binder with rubber addition are presented in Figure 11 and were found to be lower compared to the binder without any addition.

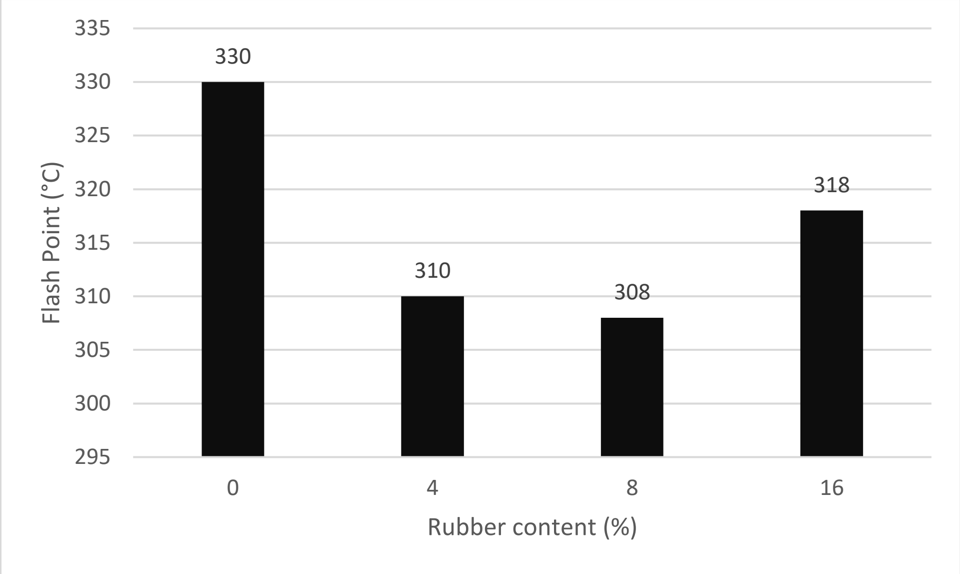

Figure 11. Flash Point.

Despite resulting in slightly lower ignition values for the material, the addition of rubber does not pose safety risks, as the results are within the specification of 235°C from [11], which specifies the minimum characteristics for the use of rubber-modified tire bitumen.

3.4 Elastic Recovery

The results of the tests are presented in Figure 12, where it can be observed that the binder with rubber addition showed expected results for the 8% and 16% rubber contents. It is also noticeable that there were higher values for the elastic recovery rate in the binder with rubber addition, indicating an increase in material elasticity.

The 4% content showed the best results, although it was unexpected, as a constant increase in elastic recovery was anticipated with the addition of rubber. It is assumed that this result may be due to a better chemical reaction between rubber and the binder, as this requires a compatible mixing time with the ratio of rubber to binder. Since the mixing time was approximately the same for all samples, it is believed that the time used may have been more favorable for mixtures with low rubber contents.

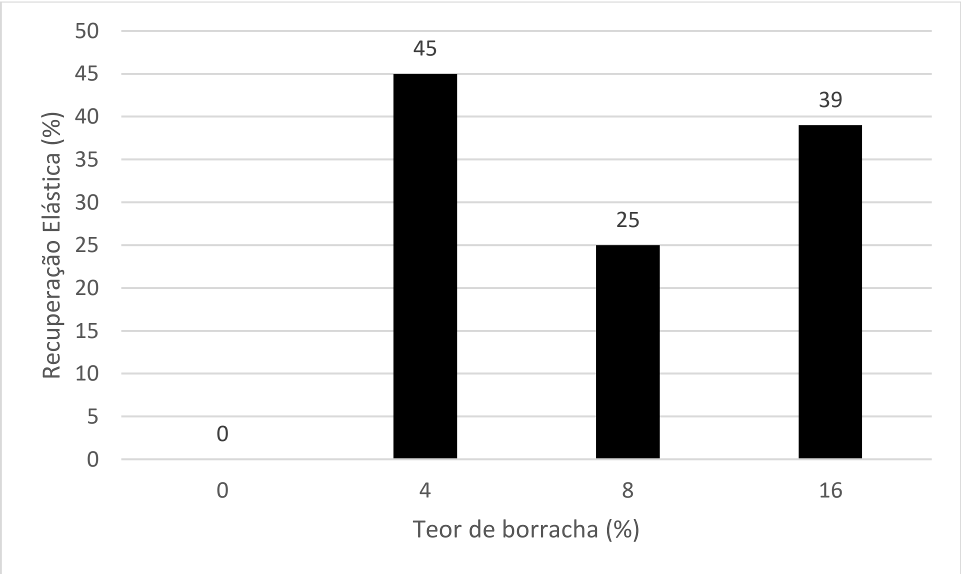

Figure 12. Elastic Recovery.

Elastic recovery is an empirical measure to determine the cohesion of the binder, which is directly related to its consistency and the attractive forces between particles [18]. Therefore, it can be concluded that an increase in rubber addition indicates an increase in shear resistance and ductility, which can reduce cracks in the pavement, as its elasticity promotes greater capacity to absorb the stresses from traffic and temperature variations [16].

3.5 Saybolt-Furol Viscosity

The results of the Saybolt-Furol viscosity tests are shown in Figure 13, and they exhibited expected viscosity results. It was observed that the higher the rubber addition, the lower the viscosity, resulting in longer flow times for the sample. It is worth noting that it was necessary to perform the test more than once for the 16% content, as in the first test, the device's opening was partially obstructed. This result can be attributed to the use of non-optimized techniques and processes for rubber incorporation into the CAP, requiring further investigation with the use of a mechanical mixer and diluents in the mixture for more precise results.

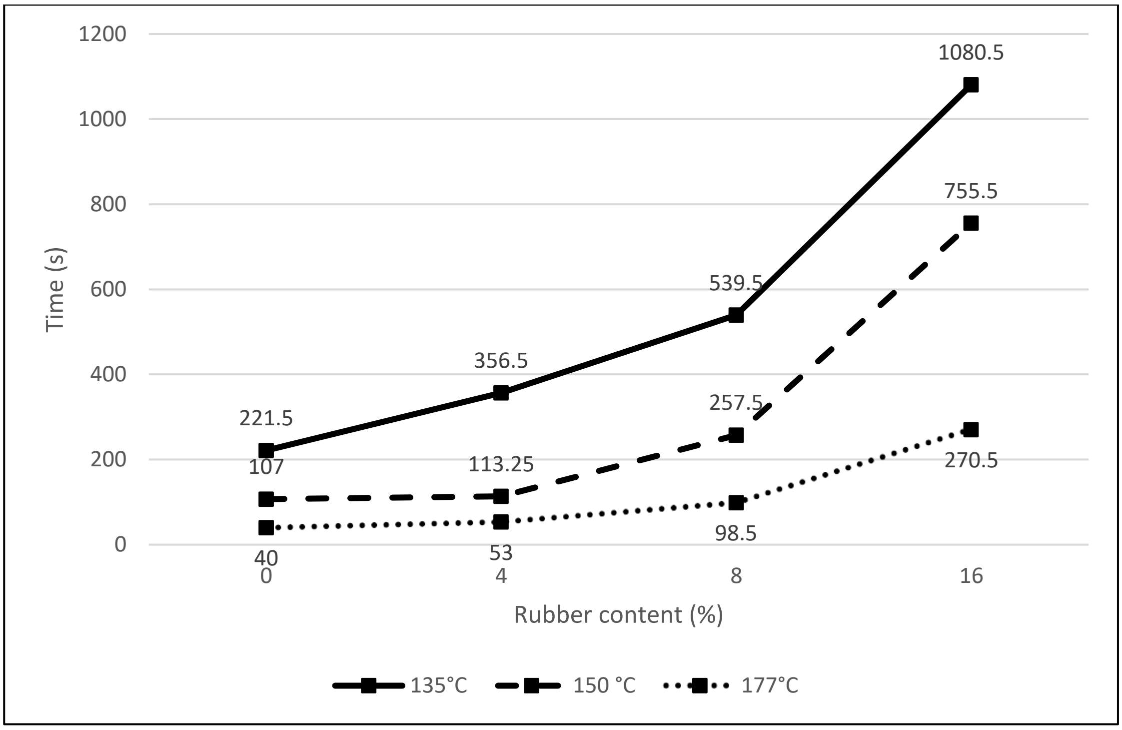

Figure 13. Saybolt-Furol Viscosity.

[8] state that viscosity is often used as a parameter for determining the mixing and compaction temperatures of AC-RAP (Asphalt Concrete with Reclaimed Asphalt Pavement) and as one of the parameters to analyze to verify binder compliance. The [11] determines the necessary specifications for rubber-modified asphalt cements, but it does not provide specifications for the Saybolt-Furol viscosity test. Since this test does not have any specified standards, neither Brazilian, American, nor European, there is no expected minimum parameter.

3.6 Technical Viability

Despite the method used for rubber incorporation into the CAP not having defined specification standards, an attempt was made to compare the results obtained with the specifications for conventional binders without any addition, binders modified with rubber powder, and binders with rubber incorporation by the wet process known as Terminal Blending. The parameters of technical feasibility were verified based on the current standards for each type of binder. The binder without any addition was specified by [6], the binder modified with ground tire rubber was established by [7]. The binder modified with tire rubber through the Terminal Blending process is standardized by [11].

For comparison, the tests conducted in this study were used as parameters, except for the Saybolt-Furol viscosity test, which is not included in this verification due to the absence of standardized specifications.

Through the following Table 3, it is possible to compare the obtained results and the specifications for each type of binder in a straightforward manner.

Table 3. Regulatory Specifications for Binders.

Technical Feasibility – Rubber-Modified CAP 30/45						
Test	Results of Samples			Specifications Minimum Requirements		
	4%	8%	16%	ANP nº 19	ANP nº 39 (AB8)	DNIT 111/09
Softening Point (°C)	52,9	57,2	64,8	52	50	55
Penetration (0,1mm)	35,4	34,2	30,3	30/45	30/70	30/70
Flash Point (°C)	310	308	318	235	235	235
Elastic Recovery (%)	45	25	39	-	50	50

It can be observed that for the softening point, the only result outside the specified range is the 4% addition compared to the Terminal Blending type standard. For the penetration results, it can be considered that all values for the additions are within the specified range in all analyzed standards, as well as the flash point results, which are also within all the specifications under study. The elastic recovery results are all below the minimum specifications of the standards analyzed. In order to obtain satisfactory results in this regard, it is recommended to use phosphoric acid (PA 85), as confirmed by [17]. Asphalt binders modified by polymers show improvements in elastic recovery due to the use of acid.

IV. CONCLUSIONS

Analyzing the obtained results, it was possible to conclude that the addition of tire rubber to the binder improves the binder's behavior, with notable improvements in consistency, elasticity, and resistance to permanent deformations.

In general, the 16% addition showed the best results, as evidenced by the Penetration, Softening Point, and Flash Point results, which were superior to all other samples. The 16% content also had the second-best result for elastic recovery, but it had the worst results in the Viscosity test, which faced difficulties during execution.

Regarding the comparison with the specifications standards for binders, except for the elastic recovery test, all samples showed satisfactory results, except for the 4% content, which did not meet the softening point requirement of the [11].

The lower values of elastic recovery compared to the values stipulated by the [7] and [11] were attributed to the use of simple processes for rubber incorporation, where mixing was done manually and without the use of industrial processes as required by such standards.

The quality control of the rubber mixing step was the most relevant factor influencing the expected results for the tests. It is necessary to use a mechanical mixer to analyze the influence of rubber incorporation more accurately. However, the use of tire rubber proved to be beneficial and satisfactory.

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