Mechanical Analysis of Asphalt Pavements with Alternative Materials in Manaus – Amazonas

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Abstract

Pathologies in urban roads are common and recurring problems in the municipality of Manaus - AM, where defects have appeared early and successfully, especially the climatic condition of the differentiated region and the non-participation of the coarse aggregate in the asphaltic coating and sublayers. predominantly made of clay. Nevertheless, the Government often performs simple "hole-covering" operations to recover and restore such a structure, corroborating all the problems that trigger poor paving in the State Capital of Amazonas. Another challenge of the municipal administration is the disposal of construction waste, making it necessary to recycle it, highlighting the serious environmental problem caused by the extraction of the pebble. Aiming to contribute with alternatives the scarcity of stone material and the natural aggregate (pebble), substitute of gravel in the regional civil construction, it is proposed the use of construction and demolition waste (RCD). Asphalt concrete (AS) mixtures were made with recycled material, residual sand, portland cement, petroleum asphalt cement (CAP 50/70) and this binder modified with the addition of SBS (styrene and butadiene copolymer). Characterization tests were performed with aggregates, filler and petroleum asphalt cement (original and polymer), dosed by the Marshall method, and the asphalt mixtures were subjected to the Beam Fatigue Test at three different stress levels. The studies indicated satisfactory results of asphalt mixtures with the participation of RCD and SBS binder, compared to regional composites.

Keywords: asphalt pavement; construction waste; fatigue.

1. Introduction

Manaus' asphalt pavements have historically shown problems, stemming from several factors: vehicle growth, lack of maintenance, severe regional climate conditions such as high temperatures and high rainfall during most of the year, and above all, technically structured structures. inadequate, either by asphalt coating as a rule using hot machined asphalt sand, or by sublayers made up predominantly of clay material. Such asphalt mortar coatings have a significant and premature deterioration process, mainly due to the fact that regional asphalt mixtures do not present the coarse aggregate as their participant and the use of low support sublayers. The capital of the state of Amazonas has its rocky top at depths generally greater than 5m. Areas of interest for exploration of these mineral resources are more than 200 km to the north. They are, therefore, at great distances from the urban area of Manau, which results in high transportation costs. In this context, the solution commonly used in regional civil construction has been the replacement of stone material by pebble deposits, causing serious environmental damage, as well as the widespread use of hot-machined asphalt sand (AAUQ) coatings on clay sublayers, extreme case of the urban pavement of the Municipality of Manaus [1].

Proposing investigations to the above mentioned problems, the application of Construction and Demolition Waste (RCD) was studied, among other materials, aiming to provide not only alternative to the technical proposal (granular material for use in regional pavements) but also the environmental issue of the final disposal of these. waste produced by the construction industry [2][3].

Regarding the significant and anticipated deterioration process of the city pavements, mainly due to the fact that low-layered sublayers and regional asphalt mixtures do not contemplate the coarse aggregate as their participant, as well as the composition exhibiting an excess of fine aggregates and of binder with inadequate properties at in situ temperature. Thus, Manaus presents pavements, in general, with temperatures around 40 ° C [4], and it is increasingly necessary to use asphalt properties modifiers.

Polymer modified asphaltic binders provide excellent alternatives to address major pavement deficiencies, especially by improving properties such as thermal susceptibility, resistance to permanent deformation and thermal cracking. Among these modifiers, polymers of various types can be cited to improve binder performance [5]. Among the most used polymers in asphalt modification, the styrene-butadiene (SBS) block copolymers stand out, which improves the elastic characteristics of asphalt [6].

The modification of the asphalt composite participants for the region aims to solve the above problems, however, one must take into account the repeated load transmitted to the coating during vehicle traffic, intrinsic action the pavement fatigue life [7]. To estimate the fatigue life of asphalt mixtures, there are laboratory tests that seek to simulate the conditions of road application and those seeking a reasoned approach [8]. Most fatigue test results have been obtained through simple bending tests, in which stresses or deformations are repeatedly applied until the prismatic specimen breaks or is structurally compromised [9]. When it comes to the advantages of this type of test, we highlight the widespread use and the possibility of using the results directly in the sizing of pavements, in addition to allowing the options of testing under stress or controlled deformation [10].

In order to mechanically characterize the CA-type asphalt mixtures, by means of the four beam point fatigue test, at three different stress levels, and aiming to expose alternative solutions to the above-mentioned points, with regard to regional paving, bodies were fabricated. with the following composites: Asphalt Binder: Pure and Polymer Modified (SBS); Coarse aggregate: RCD (Construction and Demolition Waste) with two distinct particle sizes; Household: Residual Sand and Mineral Fertilizer: Portland Cement.

2. Theoretical Referential

2.1 Resíduos de Construção e Demolição (RCD)

In Brazil, it is estimated that 50% of solid waste comes from construction and demolition [11], and the proportions are equal for each of the two activities. Of this total RCD, around 65% is of mineral origin, 13% of wood, 8% of plastic and 14% of other materials [12]. Construction companies generate between 20% and 25% of waste, and self-construction works make up the remainder, making it even more difficult to control the final disposal of the RCD. In any case, the use of recycled aggregates as a substitute for natural aggregate represents a saving in Paving works, given the high cost of transportation from the consumer centers. In the United States, for example, a savings of 30% over simple graded gravel is measured [13].

In any case, the use of recycled aggregates as a substitute for natural aggregate represents a saving in Paving works, given the high cost of transportation from the consumer centers. In the United States, for example, a savings of 30% over simple graded gravel is measured [13]. The investigation of all these works has corroborated the feasibility of using the RCD in exchange for the rolled pebble and gravel, according to technical criteria linked to the behavior evidenced in the research. Composites with RCD, according to the researches examined, showed successively better results, either in terms of stability, tensile strength or susceptibility to permanent deformation.

2.2 Vida de Fadiga

Fatigue is the process of structural deterioration that a material undergoes when subjected to a state of repeated stress and strain, and may not reach the ultimate strength of the material, resulting in cracking after a sufficient number of loading repetitions. In other words, fatigue is the loss of resistance that a material suffers when repeatedly asked for bending or traction [10]. In the fatigue test, the material is subjected to the request at which irreversible evolution occurs to a final stage of rupture or an arbitrary limit of deformation [19]. With the objective of estimating the fatigue of asphalt mixtures, there are laboratory tests that try to simulate the conditions of request of a highway and those that seek a reasoned approach [20]. Laboratory equipment for repeated load testing allows the application of cyclic loading to the material under stress and controlled deformation. In both tests there is a reduction of the initial stiffness of the material to a level that can be pre-set in order to define the end of the test. The great advantage of the DC test is that it allows better observation of fatigue crack propagation [21].

3 Methodology

3.1 Materials

The materials used in this work are easily found in the region and the methods followed were those recommended by the National Department of Transport Infrastructure - DNIT [19], Brazilian Association of Technical Standards - ABNT [22], American Society for Testingand Materials - ASTM [23] and EuropeanCommittee for Standardization - EN [24].

3.1.1 Petroleum Asphalt (CAP) and Polymer Cement

Two types of asphalt were analyzed in this research: petroleum asphalt cement (CAP 50/70), which will be called here only CAP, representing the asphalt commonly applied in the rolling layer of that city, supplied by the Isaac Sabbá Refinery (REMAN).), as well as the same binder modified by the styrene, butadiene and styrene (SBS) copolymer. A set of equipment was used consisting of a mechanical stirrer with shear propeller coupled to a thermometer and a heating blanket. The CAP 50/70 was first heated and then passed through a 5 liter Becker and directed into the heating blanket. SBS granules were then incorporated into the asphalt Becker at a ratio of 2% of the heated binder mass contained in said Becker. During the two hours of mixing of these components, the heating temperature was controlled in the range of 150 ± 5 ° C at a rotation of 300 rpm and then the modified CAP (CAPSBS) was obtained. Both binders were characterized in the local refinery's Product Development laboratory, following standard ASTM instructions [23] and meeting the requirements of the National Oil, Gas and Energy Agency - ANP [25]. The tests performed were: Penetration, Softening Point, Trichlorethylene Solubility, Flash Point, Ductility at 25 ° C, Relative Density at 25 ° C, SayboltFurole Viscosity Brookfield Viscosity (135 ° C, 150 ° C and 177 ° C), Rotational Thin Film Heat and Air Greenhouse (RTFOT) Aging, as well as post-aging tests such as Mass Variation, Retained Penetration and Softening Point Variation. With these characteristics it was possible to have a prospection of the changes caused to the asphalt with the inclusion of the polymer.

3.1.2 Mineral Material

As an alternative material in the condition of coarse aggregate, we used the Construction and Demolition Waste (RCD), coming from the crushing of beams and pillars, ie, reinforced concrete for structural purposes only (Figures 1 and 2). The composition was performed in two particle sizes, a coarse called RCD 1, because it is similar to the definition of Brita 1 (material with a maximum diameter of 19.0 mm) and a fine called RCD 0, similar to the definition of Brita 0 (material with a maximum diameter of 12.5 mm), the purpose of this mixture of particle size was to search for a well graded particle size curve (Figures 3 and 4). As a material traditionally used in Manaus, was the Manaus sand (Figure 5), material constituent of the mixtures under study.

Figure 1. Construction and Demolition Waste Storage - RCD

Figure 2. RCD block crushing and sieve separation

Figure 3. RCD Material 1 - Large Aggregate

Figure 4. RCD Material 0 - Large Aggregate.

The samples were characterized according to DNIT [19], by the following tests: Los Angeles Abrasion, Adhesiveness, Absorption, Shape Index, Apparent Relative Density, Real Density, Effective Density, Particle Size Analysis, Loose and Compacted Specific Mass, Mass Grain Specific and Sand Equivalent. Also included in the asphalt mixtures were: Portland cement (CP II – Z – 32) as filler (inert mineral material in relation to the other components of the finely divided mixture, passing at least 65% in the 0.075 mm aperture screen square mesh), being characterized by Particle Size Analysis and Real Density.

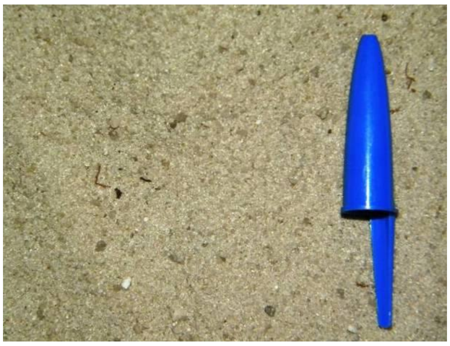

Figure 5. Manaus Sand Material - Kid Aggregate

3.2 Methods

The materials specified above were dosed according to the Marshall methodology, being asphalt concrete - CA, with CAP 50/70 and CAP 50/70 modified by SBS copolymer. The design content for both types of mixtures (RCD + CAP and RCD + CAPSBS) is determined. After obtaining the design content, the prismatic specimens were molded (Figure 6) for the stress controlled fatigue test (TC) by three stress values (0 kN, 0.7 kN and 1 kN) using the Four Point BendingApparatus equipment manufactured by IPC Global.

Figure 6. Fatigue test specimen

3.2.1 Mineral Dosage

Manauara reality is the dosing of this coating only with fine aggregates, filler and asphalt cement, or at most asphalt concrete (CA) with gravel, which in this work will be replaced by alternative coarse material. The mineral particle size of the resulting CA-type blends fell within the C (Rolling Layer) range alluding to DNIT 031/2006 - ES using Marshall dosing parameters.

3.2.2 Project Content Determination

The optimal binder content of asphalt mixtures was defined by the DNIT's 3rd Federal Road District (3rd DRF) method [19], which is based on the Void Volume (Vv) and Bitumen-Void Ratio (RBV) values. and according to the specification of the Marshall Dosing Method [26]: Vv from 3% to 5% and RBV from 75% to 82%. This method consists of determining these parameters for five groups of cylindrical specimens (101.5mm in diameter and 63.5 ± 0.5mm in height), each group having three specimens made with the same binder content. The preparation and compacting temperatures of the mixtures are obtained.

3.2.3 Confecção das Misturas Asfálticas em Molde Prismático

Concerning the production of the asphalt mix beams, removable "L" shaped metal molds were made, measuring 402 mm in length and 164 mm in height, with a 5 mm thick plate (Figure 7). 50 mm high, 400 mm long, 50 mm wide (Figure 8) and a socket with the Marshall compression standard (Figure 8), all beams were compacted at 75 strokes per face with manual compression, equivalent to a pressure of 7 to 14 kgf / cm². And with the so-called "optimum" content, the specimens were produced to perform the beam fatigue test. Therefore, it was necessary to make beams from asphalt mixes according to EN 12697-24 / 2004, whose recommendation is a minimum height of the beams of 3 (three) times the maximum diameter of the aggregate. The maximum diameter of the coarse aggregate used was 2.4 cm, ie a minimum height of 7.2 cm. However, the maximum space available on the mechanical test equipment is 6.4 cm, therefore, the minimum height adopted. There were no problems with the minimum width and length required.

Figure7 Removable L-shaped mold.

Figure 8. Mix Compaction Set

Figure 9. Inserting Asphalt Mix into Mold

Figure 10. Beams ready for Fatigue Testing

In Table 1 below, the geometric characteristics of the beams produced are discriminated, the values correspond to the arithmetic means of four measurements collected in the PC and inserted in the software that performs the test.

Table 1. Geometric characteristics of the beams.

Mixture	Indication	Altura (mm)	Height (mm)	Width (mm)
RCD+CAP	1	63,8	400,0	50,0 mm
RCD+CAPSBS	2	63,9	400,0	50,0 mm

3.2.4 Ensaio de Fadiga em Quatro Pontos de Viga

The main characteristics of the four-point bending test [24] are listed:

a) The two inner and two outer supports are symmetrically opposed to the center of the specimen.

b) The test may be performed with Controlled Deformation (DC) and Controlled Stress (TC).

c) The semi-sinusoidal loads were applied to the two inner supports in the vertical direction, while the vertical position of the external supports was fixed, Figure 11.

The equipment used to perform this experiment was the Power Point BendingApparatus, manufactured by IPC Global, which is a hydraulic or pneumatic loading machine that allows to control a very specific system and allows testing of a diverse range of specimens from small metal samples. , asphalt, fibers, plastics and similar materials, up to very large components or assemblies [21].

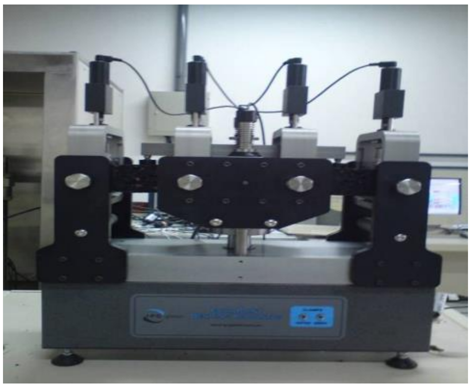

Figure 11. Four point flexion test scheme

Regarding the beam fatigue test, which was used the four-point bending equipment, the following criteria were followed:

a) Testing by controlled voltage (TC), with loading voltages of 0,3 kN, 0,7 kN and 1 kN allowed;
b) Constant test temperature of 25 ° C;
c) Test performance frequency of 10 Hz, the standard stipulates frequencies between 0.1 Hz and 50 Hz, as the frequency of 20 Hz, for example, simulates a heavy vehicle at a speed of 133 km / h on the floor. Due to this, the frequency of 10 Hz was adopted;
d) Loading range in the order of 250 µm / m;
e) Maximum number of 1,000,000 cycles;
f) Initial stiffness module calibrated in cycle number 100;
g) End of the test by obtaining complete Fatigue (rupture) or acquiring 50% of its initial stiffness modulus (stress / strain ratio).

4. Analysis and Discussion of Results

4.1 Characterization of Asphalt Binders

Table 2 lists the results of the characteristics of petroleum asphalt cements, standardized by the ANP [25]. The importance of these results is highlighted, as they directly influence the behavior of asphalt mixtures.

Table 2. Characterization of Asphalt Binders

Características	Method	Unity	Results	
			CAP 50/70	CAPSBS
Penetration	D5-06	0,1 mm	69	39,5
Softening point	D36/D36M-09	grau C	49,7	52,5
SayboltFurol Viscosity a 135 ºC	E102/E102M-09	s	283	300,78
Brookfield Viscosity a 135 ºC	D4402-06	cp	539	870
SayboltFurol Viscosity a 150 ºC	E102/E102M-09	s	140,7	149,38
Brookfield Viscosity a 150 ºC	D4402-06	cp	279,8	401,36
SayboltFurol Viscosity a 177 ºC	E102/E102M-09	s	50,8	56,97

Brookfield Viscosity a 177 ºC	D4402-06	cp	96,8	158,64
Ductility	D113- 07	cm	> 100	41,5
Flash point	D92-10	grau C	318	324
Solubility in trichlorethylene	D2042- 09	% massa	99,9	99,7
RTFOT % mass change	D2872- 04	%	0,04	0,075
RTFOT softening point increase	D36/D36M-09	grau C	7,1	9,3
RTFOT retained penetration	D5-06	%	63	27,1
Relative density 20/4 ºC	D70-09	N/A	0,998	0,994

The reduction of conventional binder penetration (CAP 50/70) is clear by adding the SBS copolymer. This result indicates increased consistency, also observed by the softening point gain (temperature required for a standard sphere to pass through a binder sample). Therefore, the increase in flow resistance is justified by the SayboltFurol and Brookfield viscosity tests. It is also emphasized the properties after aging in RTFOT greenhouse, which is observed the increase of the consistency of both asphalts, pointed by the increase in the softening point. Note that this last test is very important because it simulates the hardening of the binder in the process of machining and transport of asphalt mixtures.

4.2 Characterization of Aggregates

Listed in Table 3 and Figure 12 are the results of particle size analysis by sieving, characterization of coarse aggregates and fine, and it should be emphasized that the Portland cement presented real relative density equal to 3.16.

Figure 12 shows the particle size curve of the aggregates. It should be noted that this characteristic is one of the most important for the behavior of asphalt mixtures, influencing the stiffness, stability, workability and permanent deformation. suitable for paving, so it is necessary to verify some characteristics, whose results are presented in Table 3.

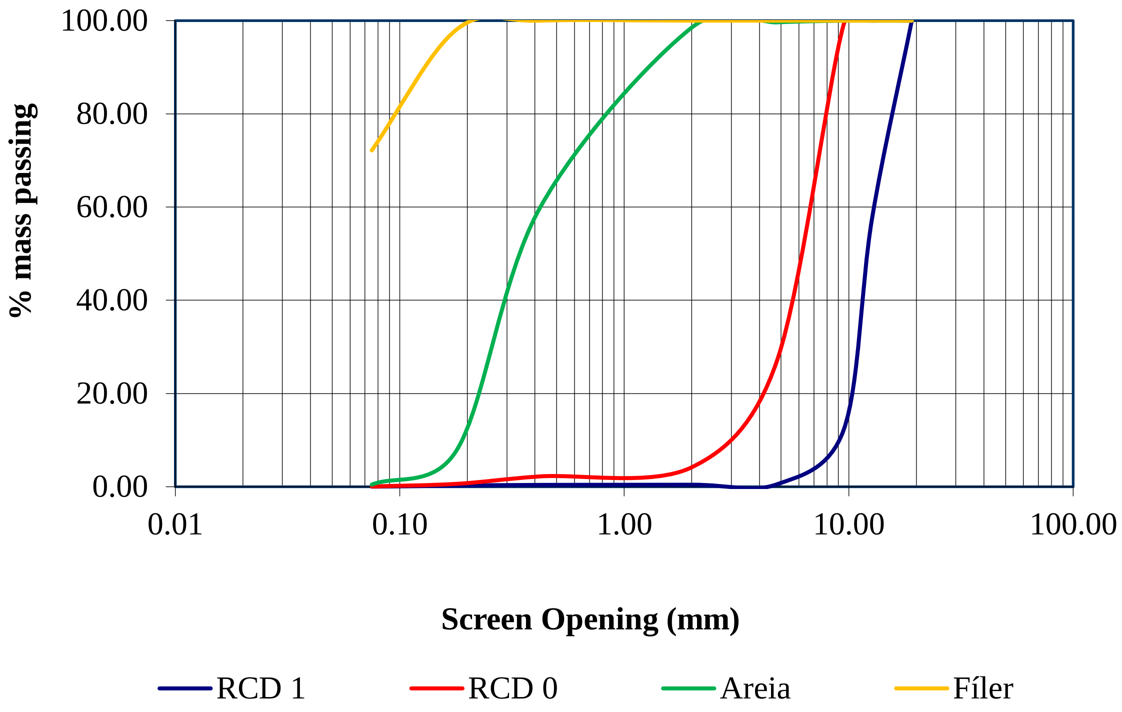

Figure 12. Aggregate Particle Size Curves

After particle size analysis, which is very important in the dosing process of an asphalt mixture, the importance of the particle shape that directly influences the workability and shear strength of the asphalt mixtures is also highlighted, that is, in general the greater the irregularity. of the larger aggregates is the interlocking of these particles in the compacted mixtures.

Table 3. Characterization of aggregates

Test	Method	RCD 1	RCD 0	Sand
Abrasion Los Angeles (%)	ME 035/98	47,34	46,81	-
Adhesiveness	ME 078	Positiva	Positiva	-
Absorption (%)	C 127 e ME 194	7,122	7,122	-
Apparently density		2,403	2,403	-
Real density		2,617	2,617	0,522
Effective density		2,165	2,165	-
Effective density (%)	D 2419	-	-	91,40
Shape Index	ABNT 6954/89	Cúbica	Cúbica	-
Loose Specific Mass (g/cm^3)	C 29	1,231	1,285	1,720
Compacted Specific Mass (g/cm^3)		1,340	1,291	1,936
Grain Specific Mass (g/cm^3)	ME 084/95	-	-	2,632

RCD 1 and RCD 0 were found to be classified as cubic, which may contribute to better performance in asphalt coatings [22]. A caliper was used to measure its dimensions (length, width and thickness) and thus obtain its classification. work on the asphalt mixture according to the granulometry obtained to form a set in it. RCD 1 and RCD 0 work on the asphalt mixture according to the particle size obtained to form a set in it. Another noteworthy feature is Abrasion Resistance, which aims to simulate the actions of transport and application of aggregates. The RCD obtained low Wear Resistance, which did not disqualify it for this work. Aiming to participate in asphalt mixtures, it is also emphasized in Table 3 the high value of Los Angeles abrasion for the RCD, extrapolating the acceptable maximum of 45%. However, for construction waste this value is acceptable, considering higher values found in the literature relative to those obtained in this research.

The high absorption of the recyclable aggregates was observed, attributing a high consumption of asphalt in the mixture, which can be explained by the sharp overall porosity found by the RCD. Large aggregates showed positive adhesiveness, which is essential, since the aggregate that does not confer this characteristic will be easily disconnected from the asphalt film, causing pavement wear, a common pathology in Manaus coatings [27].

4.3 Mineral Dosage

Based on the maximum and minimum ranges established by DNIT [19], Figure 13 presents the granulometry of the mixture, while Table 4 shows the participating aggregates and their corresponding percentages in this research.

Table 4. Aggregate mineral dosage and filler

Material	CA RCD/CAP (%)	CA RCD/CAPSBS(%)
RCD 1	30,5	30,5
RCD 0	35,0	35,0
Residual sand	31,0	31,0
Cement	3,50	3,50

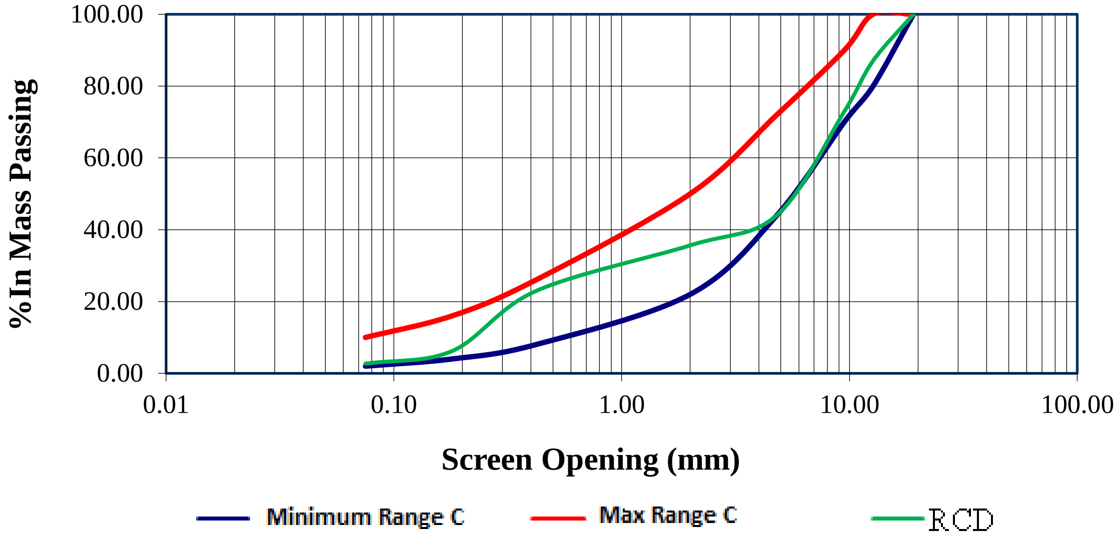

Figura 13. Enquadramento das misturas – Faixa C, Norma DNIT 031/2006-ES

4.4 Project Content

Design levels were defined by graphical process according to physical parameters and particle size analysis [19] [26]. It is noteworthy that: RCD + CAP refers to asphalt mix with traditional binder (CAP 50/70) and asphalt mix with modified SBS copolymer binder (RCD + CAPSBS).

Table 5. Mix Parameters

Mixture	Project Content de CAP (%)	Vv (%)	RBV (%)
RCD+CAP	6,91	4,00	78,40
RCD+CAPSBS	6,05	3,85	76,58

By observing the binder design content for all mixtures analyzed, there is a slight decrease in binder consumption for mixtures produced with CAPSBS compared to mixtures made with standard CAP. All Vv and RBV parameters fall within their respective standards (Table 5).

4.5 Fatigue Determination by Four Point Bending Apparatus Equipment

The fatigue test is characterized by the reduction in the strength of a material under repeated loading when compared to the resistance under application of a single load [24]. frequency, were set such that the number of cycles for the test did not last very long, over 24 hours. The initial module value is calculated at the start of the test by performing 100 cycles for its determination . Information about the Stiffness Module after the Fatigue Test is observed in the mixtures made for this research in Table 6 and Figure 14.

Table 6. Rigidity Module Results for Different Tensions

Mixture	Amplitude µm/m	Tension (kN)	Nr of Cycles	Stiffness Module (MPa)
RCD+CAP	250	0,3 kN	685.342	5.004, 67
RCD+CAPSBS			737.871	5.643,90
RCD+CAP	250	0,7 kN	498.573	5.647,23
RCD+CAPSBS			554.856	5.921,65
RCD+CAP	250	1,0 kN	239.184	6.089,51
RCD+CAPSBS			303.763	6.341,73

No specimen (beam) was tested under the same conditions as the previous one, the mix and tension were changed. Knowing that the modulus of stiffness is the relationship between stress and strain, higher stresses bring larger modules, in some cases this behavior was not observed. The composite beams with RCD (CA) were able to break clearly, observing even the ruptured coarse aggregate.

In Figure 15 it is possible to verify that with the increase of the deformation, there was a gain of the Stiffness Module, highlighting that the asphalt mixture constituted with RCD and SBS obtained the highest values of this last property, which also showed the lowest deformation values. In his work, [28] also obtained increasing linear representation, which composed asphalt mixtures that went through the aging process, whose asphalt binder was modified with recycled tire rubber.

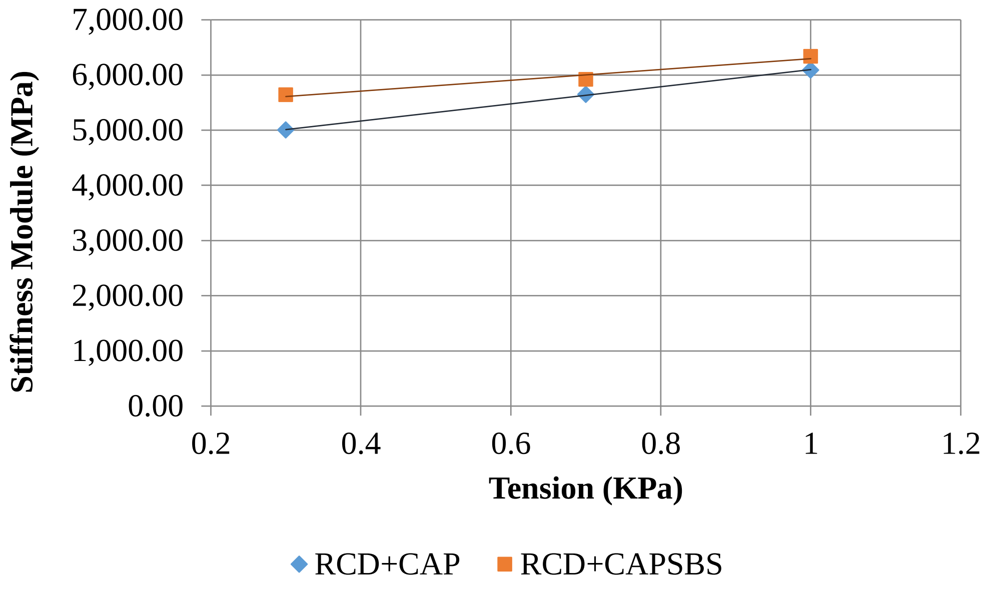

Figure 14. Rigidity x Stress Module Chart of Tested Asphalt Mixtures

The use of the SBS copolymer in the CAP provided an increase in the Stiffness Module, confirming previous studies regarding the efficiency of this particle polymer in mechanically tested asphalt composites in other parameters [17] [18]. When comparing the values presented for the mixtures with conventional PAC, it is clear that the deformations were higher than those with the modified ligand.

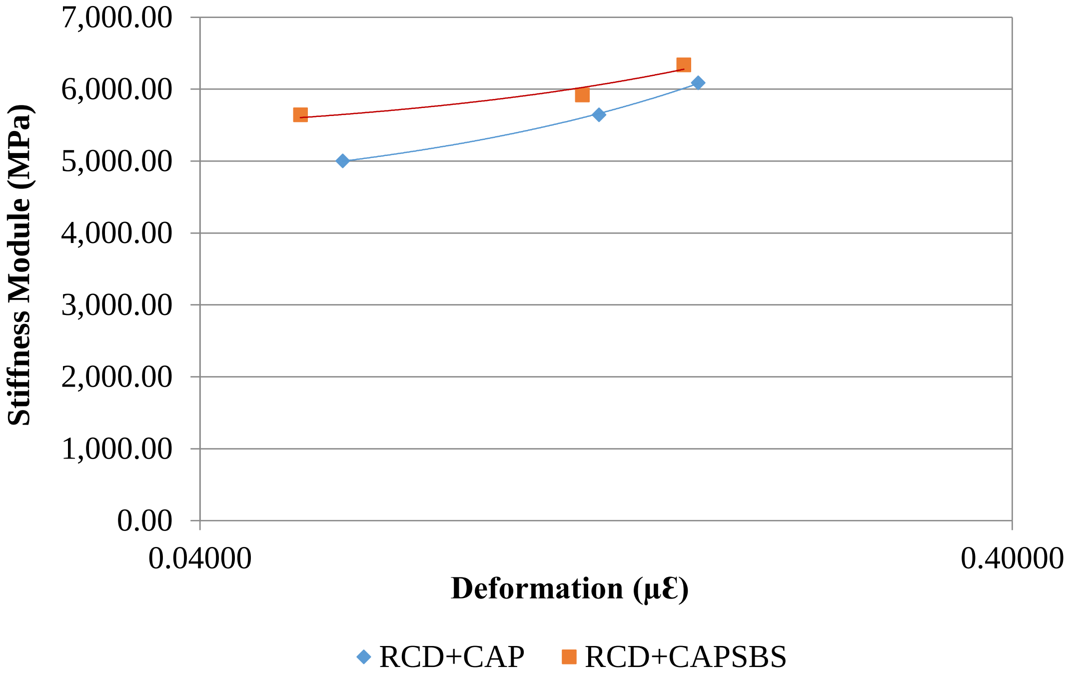

Figure 15. Stiffness vs. Deformation Module Graph of Tested Asphalt Mixtures

5 Conclusion

Aiming to contribute to the execution of alternative and viable asphalt composites for application in Manaus urban roads, specimens (beam type) were made in order to be mechanically characterized. It is understood that, with this research, we obtained:

a) Consumption savings of asphalt binder, as the 2% insertion of SBS into the CAP generated a slight decrease in its volume with the use of recycled aggregate.
b) Concerning the Fatigue Assay, there was an increase in specimen life within each type of mixture after incorporation of the SBS copolymer.
c) RCD + CAPSBS-containing mixtures had a longer Fatigue period than RCD + CAP-mixtures at all stress levels.
d) The RCD (Construction and Demolition Waste) aggregate, commonly called recycled, is an alternative to asphalt coatings used in urban roads in the city of Manaus, since it presents satisfactory results when compared to the materials commonly used in regional paving, besides comply with the prerequisites outlined by the standards.

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