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Stone Matrix Asphalt (SMA) com Resíduos da Construção Civil e da Fibra do Curauá (*Ananas erectifolius*)

Stone Matrix Asphalt (SMA) with Construction Waste and Curauá Fiber (*Ananas erectifolius*)

Stone Matrix Asphalt (SMA) con Residuos de Construcción y Fibra Curauá (*Ananas erectifolius*)

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Resumo

As misturas SMA se distinguem pelo alto teor de vazios, favorecendo o escorrimento do ligante asfáltico. Para evitar tal efeito, adicionam-se fibras que, nesse caso, foram procedentes do Curauá da Amazônia (Ananas erectifolius). A composição final estudada resultou em 75%

de agregado graúdo, 15% de agregado miúdo, 10% de fíler, 0,3% do resíduo da fibra do Curauá, e os teores de CAP iguais a 6.50% e 6.88% para as formulações SMA-Brita (referência) e SMA-RCD (alternativas), respectivamente. Os resultados mostraram que a Resistência à Tração para os compósitos com RCD obtiveram maiores valores. Específico ao MR, na temperatura de 25°C, verificou-se para o conjunto das composições e, em todos os níveis de carregamentos, valores com ínfimas variações. Todavia, na temperatura de 40°C, o citado parâmetro mostrou decréscimos nas duas formulações pesquisadas. No geral, em todos os níveis examinados, observou-se maiores valores para o MR da mistura alternativa (SMA-RCD). Destacam-se os resultados mais elevados desse parâmetro quando comparam-se as composições com o resíduo da fibra de Curauá e as formulações citadas na literatura, tendo a presença de outros tipos de fibras. A respeito do aumento da temperatura, comprovou-se decréscimos dos resultados para ambos os parâmetros mecânicos (RT e MR), mas com menores perdas para a composição SMA-RCD.

Palavras-chave: Stone matrix asphalt; Resíduo de construção e demolição; Fibra do curauá; Resistência a Tração; Módulo de Resiliência.

Abstract

The SMA mixtures are characterized by a high void ratio, which favors binder draindown. In order to avoid this effect, fibers are added to the mixture, which in this case came from Curauá da Amazônia (Ananas erectifolius). The final composition studied resulted in 75% coarse aggregate, 15% fine aggregate, 10% filler, 0.3% of the Curauá fiber residue, and CAP contents equal to 6.50% and 6.88% for the formulations with SMA-Crushed Stone (reference) and SMA-construction and demolition waste (alternative), respectively. The results showed for the Tensile Strength that the composites with CDW reached higher results. The Resilient Modulus values presented small variations for the set of compositions in all loading levels at a temperature of 25°C. However, at a temperature of 40°C, the aforementioned parameter presented decreases in both researched formulations. In general, at all levels examined, higher results were observed for the alternative mixture (SMA-CDW). It is noteworthy the highest results of this parameter when comparing the compositions with the Curauá fiber residue and the formulations mentioned in the literature, with the presence of other types of fibers. Regarding the increase in temperature, there was a decrease in results for both mechanical parameters (TS, DM), but with lower losses for the SMA-RCD composition.

Keywords: Stone matrix asphalt; Construction and demolition waste; Curauá fiber; Tensile strength; Resilient modulus.

Resumen

Las mezclas SMA se distinguen por el alto contenido de vacíos, favoreciendo la escorrentía del ligante asfáltico. Para evitar este efecto, se añaden fibras que, en este caso, procedían de la Curauá da Amazánia (*Ananas erectifolius*). La composición final estudiada dio como resultado un 75% de áridos gruesos, el 15% del árido fino, el 10% del filler mineral, el 0,3% del residuo de fibra curauá y el contenido de la Cemento Asfaltico de Petróleo (CAP) igual al 6,50% y al 6,88% para las formulaciones SMA-Grava (referencia) y SMA-RCD (alternativa), respectivamente. Los resultados mostraron que la resistencia a la tracción (RT) de los compuestos con RCD obtuvo valores más altos. Específica del Módulo de Resiliencia (MR), a una temperatura de 25°C, se verificó para todas las composiciones y, en todos los niveles de carga, valores con pequeñas variaciones. Sin embargo, a 40°C, el parámetro antes mencionado mostró disminuciones en las dos formulaciones estudiadas. En general, en todos los niveles examinados, se observaron valores más altos para la MR de la mezcla alternativa (SMA-RCD). Los resultados más altos de este parámetro destacan al comparar las composiciones con el residuo de fibra curauá y las formulaciones citadas en la literatura, con la presencia de otros tipos de fibras. En cuanto al aumento de temperatura, se verificaron disminuciones en los resultados para ambos parámetros mecánicos (RT y MR), pero con pérdidas más bajas para la composición SMA-RCD.

Palabras clave: Stone Matrix Asphalt. Residuos de construcción y demolición; Fibra del curauá; Resistencia a la tracción; Módulo de resiliencia.

1. Introduction

The premature deterioration of urban roads through wheel track rutting, surface abrasion and cracking, may arise, among other reasons, from the regional geotechnical particularities represented by the insufficiency of superficial natural raw materials, which would impede the presence of gravel within the pavement layers. Such specificities are exemplified by the emblematic conjuncture of much of the Brazilian Amazon. In this context, the alternative, in general, has been the replacement by pebble. However, both materials generate environmental impacts. In particular, crushed stone presents in its extraction process, by means of explosions for the extraction of the blocks of rocks, an expressive vibration in the substrate and the release of powdery material, which spreads quickly through the air. As for pebble, its removal causes changes in the river dynamics, besides compromising the riparian forest and the fauna, thus drastically altering the landscape aspects of the place.

Therefore, it is necessary to revalue nature through environmental preservation, which leads to the research for ways of using natural resources and industrial by-products as alternative sustainable materials for the use in civil construction, such as in pavements. Natural fibers fit in this context, as exemplified by the Amazonian Curauá fiber, Ananas erectifolius. An economically profitable material with an outstanding performance from a mechanical point of view, as it provides tensile strength superior to those derived from coconut, sisal or jute, reaching physical characteristics near fiberglass and linen (Zah, Hischier, Leão, & Braun, 2007). In the current scientific panorama, there have been no studies regarding the presence of this input in asphalt mixtures. However, relevant studies stand out by analyzing the addition of this fiber in dosages of Portland cement concrete, demonstrating a positive performance in terms of tensile strength and water absorption (Soltan, das Neves, Olvera, Savastano Junior, & Li, 2017; Souza, Souza, & Silva, 2017).

We should also mention within this scenario of environmental preservation, certain technical studies regarding crushed aggregates originated from the by-product of reinforced concrete and discarded by the construction industry, the so-called construction and demolition waste (CDW), which present excellent results as a replacement for aggregates. (Roy, 2020), (Gómez-Meijide & Pérez, 2013), (Ossa, García, & Botero, 2016), (Medina, Zhu, Howind, Frías, & De Sánchez Rojas, 2015), (Kowalski et al., 2016), (Gómez-Meijide & Pérez, 2014), (Tahmoorian & Samali, 2018),.

In the present study, the asphalt mixture of the Stone Matrix Asphalt (SMA) type is examined, which compared to the traditional Asphalt Concrete (AC) contains a higher percentage of coarse aggregates, forming a compact and interlaced structure that favors the dissipation of the load, presenting both resistance to permanent deformation as wear resistance. Such composites have a high void content, leading to the inclusion of fibers, aiming especially at preventing the leaking of the binder. (Ameli, Babagoli, Norouzi, Jalali, & Poorheydari Mamaghani, 2020; Habibnejad Korayem, Ziari, Hajiloo, Abarghooie, & Karimi, 2020) In particular, the mechanical performance of these asphalt formulations is researched, using industrial by-products of civil construction, as well as residues of raw materials extracted from the Amazon rainforest, contributing to the development of regional asphalt formulations as well as to new materials for pavement engineering.

2. Materials and Methods

The work in question consisted of a laboratory research with the obtaining of quantitative data from the physical characterization of the materials of the mixtures of the SMA type, the determination of the best composition with the mentioned materials, and the mechanical behavior according to the Indirect Tensile Strength (TS) and Resilience Modulus (RM). According to Pereira et. al (2018), this experimental approach allows to simulate performance in the field.

2.1 Materials

2.1.1 Mineral Aggregates and Asphalt Material

The following mineral materials were used for this study: crushed granite sold in the Municipality of Manaus, representing the traditional coarse aggregate; crushed construction and demolition waste, corresponding to the alternative coarse aggregate; residual sand, participating as the fine aggregate; and Portland cement CP II- Z-32, taking part as a filler. Initially, the aforementioned materials were analyzed for texture, through the results of the sieving test (ASTM C136: 2014). These data are relevant for framing the components of the asphalt mixture into the SMA coating granulometry, which aims at a composition predominantly consisting of coarse particles, in order to provide a greater grain-to-grain contact.

Absorption, bulk specific gravity, (Gsa) and apparent specific gravity (Gsb) (ASTM C 127: 2015) were also determined for the coarse and fine aggregates. Specifically, regarding the coarse material, it was also analyzed for Los Angeles abrasion (ASTM C 131: 2020). As for the Portland CP-IV filler, it was defined by granulometry (ASTM C 136: 2019) and by means of its true specific mass (ASTM C 188: 2017). Finally, petroleum asphalt cement was used as a bituminous binder, being tested by ASTM standards.

2.1.2 Curauá Fiber

The Curauá fiber residues (*Ananas erectifolius*) were described in terms of length and specific mass. The fiber residues were manually cut to a length equal to 0.02m (Figure 1), since this dimension has showed a better performance according to initial testing. Regarding the actual density, it was analyzed using the ASTM C 128: 2015 standard.

Figure 1: Curauá Fiber Residue.

Source: Author (2020).

Figure 1 shows the fibers cut for use in asphalt compositions. It is noteworthy that this size was considered to be ideal, as larger dimensions could form possible tangles of fibers, thus making it difficult to disperse in the mixture.

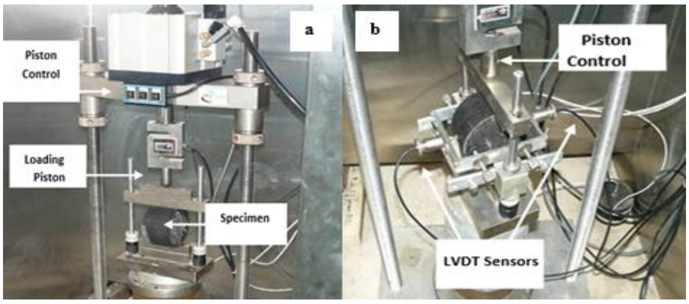
2.2 Methods

Two formulations were used, namely: SMA-CS (reference) and SMA-CDW (alternative). For both formulations, the aggregates composition followed the maximum and minimum granulometric ranges, as described in the methodology proposed by NAPA (2002), specifically regarding the maximum nominal size of 19.0mm.

For the determination of the project content, the following steps were performed: Marshall compaction, with the application of 50 strokes on each side (AASHTO M325-08); simulation of short-term aging (machining, transport and compaction in the field), inserting the samples into an oven at a temperature of 162.5°C for 2 (two) hours; the determination of Bulk Specific Gravity (Gmb), following ASTM D 1188: 2015 and ASTM D 2726: 2019, the Maximum Specific Gravity (Gmm), in accordance with ASTM D 2041: 2019, and the Air Voids volumetric parameters (AV), Voids in Coarse Aggregate (VCA) and VCA of the Coarse Aggregate Fraction (VCADRC).

The mechanical behavior of the composites was evaluated according to the Tensile Strength (TS) and Resilient Modulus (RM), using an IPC Global Universal Testing Machine (UTM). The tensile strength test by diametral compression (Figure 2a), performed at temperatures of 25°C, 40°C and 60°C, followed the methodology described in ASTM D6931: 2017. The Resilient Modulus test (Figure 2b), was based on the regulations of AASHTO TP-31-96 (2000) and ASTM D4123:1995, being performed at the temperature levels of 25°C and 40°C, a frequency of 1hz and a loading period of 0.1s (load) and 0.9s (rest), and an applied load of 5%, 15% and 30% of RT.

Figure 2: a) Tensile Strength Test; b) Resilient Modulus Test.



Source: Author (2020).

Figures 2a and 2b illustrate the Universal Testing Machine (UTM 14), with specimens conditioned in environmental chamber for temperature control. We highlight the use of Linear Variable Differential Transducers (LVDT) sensors for reading horizontal displacements (Figure 2b).

3. Results and Discussion

3.1 Physical Characterization of Aggregates and Curauá Fiber Residue

Table 1: Physical Characterization of Aggregates.

Material	Properties	Unity	Result
Construction and demolition waste (CDW)	Bulk specify gravity (Gsa)	g/cm³	2,55
	Apparent specify gravity (Gsb)	g/cm³	2,20
	Absorption	%	6,25
Crushed Stone (CS)	Bulk specify gravity (Gsa)	g/cm³	2,68
	Apparent specify gravity (Gsb)	g/cm³	2,66
	Absorption	%	0,25
Fine aggregate	Bulk specify gravity (Gsa)	g/cm³	2,65

Source: Author (2020).

Table 1 presents the density of the materials. It should be mentioned that compared to the granite aggregate, the recycled coarse aggregates presented lower results, probably due to the greater amount of voids, evidenced by their high absorption. It is also emphasized that the irrelevant porosity of the crushed stone may have contributed to obtaining values very close to the densities (real, apparent and apparent in the saturated condition). As for abrasion wear, it resulted in 17% and 44% for gravel and CDW, respectively. According to NAPA20, the maximum value of 30% is recommended for this parameter, although it considers that aggregates with values above this percentage have been successfully used.

The Curauá fiber density resulted in a value of 1.43 g/cm³. It is significantly higher in comparison to the traditional fiber typically used in SMA mixtures, derived from cellulose, whose density on average is in the range of 4.80 - 5.30 g/cm³.

3.2 Bituminous Binder Characterization

Table 2: Bituminous Binder Characterization.

Parameter measured	Test Method (ASTM)	Limits	Result
Penetration (0.1mm)	D5:2019	50-70	69
Softening Point (°C)	D36:2014	46	49,7
Flash Point (°C)	D92:2019	235	318
Solubility in Trichloroethylene	D2042:2015	99,5	99,9
Ductility	D113:2017	60	> 100
Saybolt Furol Viscosity at 135°C (s)	E102:2016	141	283
Brookfield Viscosity at 135°C (cp)	D4402:2015	274	539
Saybolt Furol Viscosity at 150°C (s)	E102:2016	50	140,7
Brookfield Viscosity at 150°C (cp)	D 4402:2015	112	279,8
Saybolt Furol Viscosity at 177°C (s)	E102:2016	30-150	50,8
Brookfield Viscosity at 177°C (cp)	D 4402:2015	57-285	96,8

Source: Author (2020).

According to the test results shown in Table 2, the Petroleum Asphalt Cement was classified as CAP 50/70. We emphasize that the properties represented by the Softening and Solubility Point in Trichloroethylene, remained close to the values indicated by ASTM, with the exception of the Flash Point, which registered a higher result, implying in a greater safety in the handling of the binder. As for Ductility, the CAP presented a fine consistency. In the case of viscosities, either at temperatures of 135 or 150°C, values higher than those recommended by ASTM were observed. However, for the temperature of 177 ° C the result remained within the prescribed.

3.3 Dosage

The final dosage for the formulations consisted of 75% coarse aggregate, 15% fine aggregate, 10% filler, 0.3% of Curauá fiber residue, with the CAP contents equal to 6.50% (SMA-CS) and 6.88% (SMA-CDW). The remaining Maximum Specific Gravity (Gmm) and Bulk Specific Gravit (Gmb) parameters resulted in 2.425g/cm³ and 2.33g/cm³ for the reference mixture, and 2.185g/cm³ and 2.09g/cm³ for the alternative composition. Table 3 shows the volumetric parameters of the mentioned asphalt mixtures. It is observed in Table 3 that all volumetric parameters remained within the limits prescribed by the NAPA methodology.

Table 3: Volumetric Parameters.

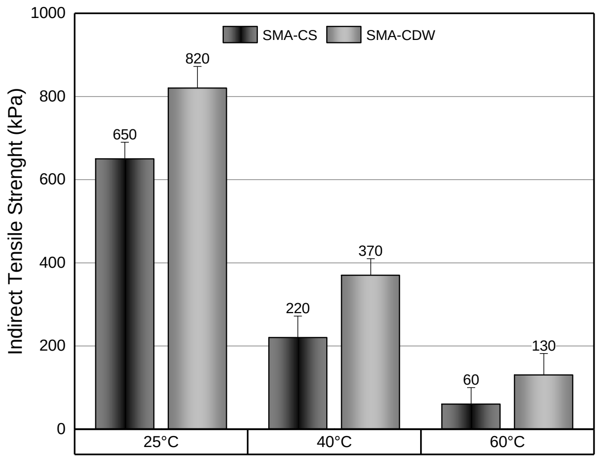
Property	Requiremernt (NAPA)	SMA-SC	SMA-CWD
Asphalt Cement, %	6, minimum	6,50	6,88
AV, %	4	4	4
VCA (%)	Less than VCA_{DRC}	12,28	4,82
VCA_{DRC}	-	45,38	42,61

Source: Author (2020).

3.4 Mechanical Characterization

3.4.1 Tensile Strength (TS)

Figure 3: Tensile Strength (kPa).



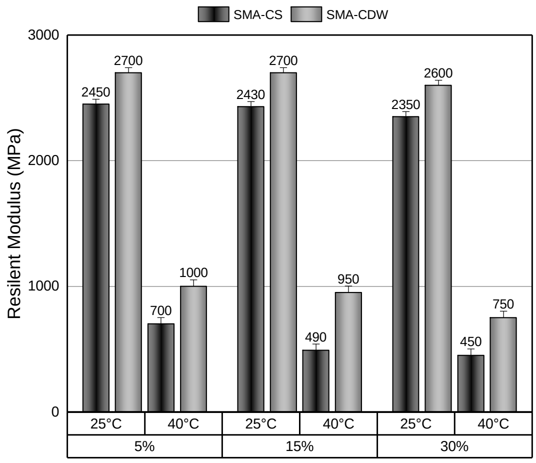
Source: Author (2020).

The results of Tensile Strength (TS) are shown in Figure 3. In the temperature transitions from 25°C to 40°C and from 40°C to 60°C, some decreases are noted. For the SMA-CS mixture, the decrease was of 66.15% and 72.72%, while for the SMA-CDW formulation, smaller reductions of 54.87% and 64.86% were registered. Regarding the replacement of the conventional coarse aggregate (crushed stone) to an alternative one (CDW) in the studied asphalt compositions, there was a remarkable applicability from a technical scientific point of view, considering that in the three studied temperature levels of 25°C, 40°C and 60°C, there was a percentage increase in mechanical strength of 26.15%, 68.18% and 116.67%, respectively.

Comparing the SMA-CDW formulation to other works described in the literature, we may mention a mixture (Cao, Liu, & Feng, 2013) composed of coarse aggregates derived from basalt and limestone, and wood fiber, in which a percentage increase of 37.80% and 41.37% was observed, respectively. Furthermore, results of asphalt mixtures (Behnood & Ameri, 2012) with the presence of the styrene-butadiene rubber (SBR) and steel slag - a material presenting high hardness and resistance to abrasion and rolling - reached an ITS equal to 700kPa, which is below the value of 820kPa achieved by the SMA-CDW composition.

3.4.2 Resilient Modulus (RM)

Figure 4: Resilient Modulus (MPa).



Source: Author (2020)

Figure 4 outlines the Resilient Modulus results, in which a Poisson's ration equal to 0.35 was applied. On average, in the results of the two mixtures of SMA-CS and SMA-CDW at a temperature of 25°C, no appreciable differences were identified, given the different TS loading levels of 5%, 15% and 30%. However, for the temperature of 40°C the values of the aforementioned parameter decreased with the increase of load. When changing the temperature from 5% to 15% of the TS, the percentage decrease consisted in 30% (SMA-Crushed stone) and 5% (SMA-CDW); when varying from 15% to 30%, the decrease was in the order of 8.16% (SMA-CS) and 21.05% (SMA-CDW). In general, at all levels examined, the alternative formulation (SMA-CDW) presented better results. In addition, we should mention the RM/TS ratio, through which a lower level may lead to a better behavior in terms of elasticity and tensile strength of asphalt compositions (Santos, Lucena, Lucena, Silva, & Costa, 2015). For the formulation composed of SMA-CS at a temperature of 25°C and 40°C, respectively, this ratio reached levels of 3615.28MPa and 2045.45 MPa. As for the SMA-CDW mixture, the results were equal to 3170.74 MPa and 2027.03 MPa. It can be observed that all these values are marked within the maximum limit of 5000 MPa, as established by the Australian standards (2012).

Finally, we emphasize a comparison between the RM results obtained in the present study, in particular the values reached by the SMA-CDW asphalt mixture at a temperature of 25°C, with other works present in the literature. As for example, data from a composition containing cellulose fibers and researched at T = 20°C, which presented laboratory results lower than those of SMA-CDW. Further references mention studies at temperatures of 25°C and 35°C, respectively, which regarding the alternative mixture and at temperatures of 25°C and 40°C, achieved results of 56.16% and 9.03% with the addition of polyester, as well as 42.39% and 4.79% with the inclusion of rock wool in the asphalt mixture (Lavasani, Latifi Namin, & Fartash, 2015; Sadeghian, Latifi Namin, & Goli, 2019).

4. Conclusion and Suggestions

The behavior of the studied asphalt compositions have allowed to conclude that the SMA-CDW mixture presented superior results of tensile strength (TS) in the three studied temperatures, when compared to the SMA-CS composition. In the case of the resilient modulus (RM), for the temperature of 25°C, minimum variations were observed in all levels of loads. However, at 40°C, there was a decrease in the RM for the two mixtures studied. Specifically regarding the compositions with the participation of the Curauá fiber, higher values were recorded when compared to formulations containing other types of fibers (cellulose, polyester and rock wool). At a temperature of 40°C, this alternative mixture also presented a better result regarding the RM/TS ratio.

Finally, for future work, it is suggested the use of kneading compaction that best simulates field conditions, as well as complementing the analysis of mechanical behavior through four-point bending and creep tests.

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