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ANALYSIS OF THE POTENTIAL FOR THE USE OF THE GREEN COCO PEEL FIBER FOR ASPHALT PAVING IN THE CITY OF RECIFE, PERNAMBUCO, BRAZIL

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ABSTRACT

Brazil is one of the largest consumers of coconut water in the world, as a result it is also one of the world's largest producers of this fruit. The green coconut shell represents around 80% of the volume of this fruit, generating a large residue after consuming its water. Thus, it ends up being a waste generated in high quantity, mainly in the cities of northeastern Brazil, which has a large extension of the coastal region. This waste, due to its shape, occupies large volumes in landfills and generates a lot of visual pollution in urban centers, mainly on beaches. Its reuse becomes a good environmental alternative to minimize the impacts generated. This research seeks to study the possibility of reusing green coco shell fiber in asphalt mixtures using the materials that make up the road pavements commonly used in Recife, Pernambuco, Brazil, analyzing the technical characteristics obtained in this mixture with the addition of green coco fiber in compared to pure asphalt mixtures. The results of this study showed a good performance of the asphalt mixture using the fiber of the green coconut shell. All parameters with analyzed Diametral Tensile Strength, Stability and Creep showed results within the parameters acceptable by the standards. For some tests, the results for mixtures with addition were better than those performed for pure mixtures, as was the case of Cântabro Wear and the Water Susceptibility Index. Therefore, asphalt mixtures with the addition of green coconut fiber have shown good results and can be a good alternative.

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INTRODUÇÃO

In recent years, it has been noted the intensification of coco cultivation areas in various parts of the world, in Brazil the situation is no different, according to the Food and Agriculture Organization of the United Nations (2018) Brazil is the fourth largest producer world, second only to Indonesia, the Philippines and India. This growth is driven by the promising trend in the production of its water, the consumption of which is associated with quality of life and health (Matos, 2017).The accumulation of shells, waste generated by the consumption of green coco, in inadequate locations in the urban area, in addition to causing a deleterious effect on the image of the city, has caused a series of economic and environmental problems for the municipalities, since it affects municipal waste collection, transportation and disposal services, due to the large volume it occupies and the decomposition time that can reach 12 years. Along with this, its shape and constitution make it difficult to compact, which increases the demand for landfill area and causes a reduction in their useful life (Corrandini *et al.,* 2009).However, studies such as those carried out by Tenório& Santos (2018) who studied the reuse of green coco shell in plasterboard and in the production of containment blankets prove that can be reused in several ways. Its reuse in road paving can be a good alternative, in the Brazilian scenario, as this is the main modal of cargo transportation, and the main logistical transportation system with approximately 62% of the flow of national production, with a network of 1,752,868 kilometers of highways, being the fourth largest in the world (Hughes, 2017).Given the above, the possibility of reusing green coco shells in road works becomes an important economic and environmental action in the Brazilian panorama, which is also reflected in the City of Recife / PE, which is a high consumer of green coco and has serious problems with the road network it serves, due to the scarcity of deposits of materials and the occurrence of subgrade with low capacity soils. Oliveira *et al.* (2016), found that the plain of the City of Recife, capital of the state of Pernambuco (PE), Brazil, has its origin in the accumulation of sediments brought mainly by the action of the sea and rivers. It contains peat, silt, shells, and other types of materials, but there is a predominance of soft organic clay soils.Thus, this work aims to evaluate the possibility of using green coco shell fibers in asphalt mixtures produced in Recife / PE, thus finding a way to reduce the disposal in landfills, optimizing the use of aggregates in asphalt mixtures and still achieve a floor with greater durability.

MATERIALS AND METHODS

For the development of this research, the main characteristics of the materials that made up the Asphalt Mixture were analyzed, through laboratory tests using the materials that make up the vast majority of asphalt mixtures produced in Recife / PE and in its metropolitan area. The research consisted of structuring Asphalt Mixtures using green coconut shell fiber in some proportions / percentages and measuring its technical characteristics as the percentage of green coconut fiber in the mixtures increased and comparing one using the same materials without the addition of coconut fiber green. The flowchart shown in Figure 1 shows the sequence used in the development of the research.

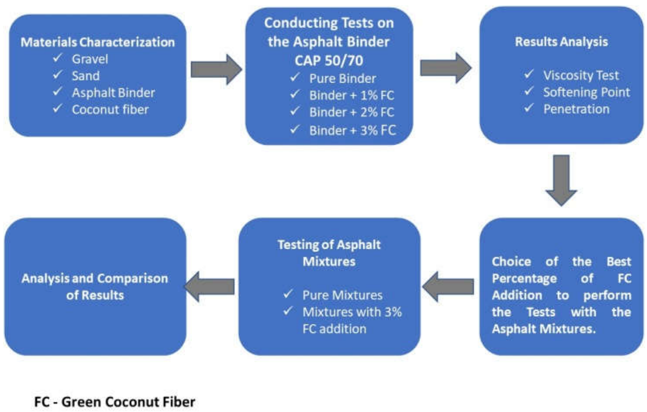

Figure 1. Flowchart of the sequence used in the development of the research. The authors (2020)

Materials Characterization

Aggregates: The aggregates used in the paving of Recife / PE and the metropolitan area were supplied by Pedreira Guarani. This material source is a commercial quarry used for more than 10 years located in Jaboatão do Guararapes / PE. For the composition of the Mixtures, samples of 12mm and 19mm gravels, of the Stone and Sand Powder obtained through collections in the Guarani quarry deposits were used and the tests presented in Table 1 were carried out, for technical characterizations of these aggregates.

Table 1. Tests performed on aggregates

Test	Method
Granulometry analysis	DNIT – ME 083/98
Sand Equivalent	DNIT – ME 054/97
Los Angeles Abrasion	DNIT – ME 035/98
Adhesiveness	DNIT – ME 078/98
Shape Index	DNIT – ME 086/94

Source: The authors (2020)

Asphalt Binder: According to Almeida Júnior et al. (2018) asphalt mixtures have viscoelastic and thermo-susceptible characteristics from asphalt binders, which, depending on the type and content, are more or less susceptible to variation in temperature, frequency and time of load application and to present permanent deformation at high temperatures. The asphalt binder used was CAP (Petroleum Asphalt Cement) 50/70, supplied by a company, Located in the state of Ceará, Brazil. This material is widely used by Companies that perform paving services in Recife and metropolitan area.

Green Coconut Fiber: According to Santos (2018) in the past, coconut fibers were used in the manufacture of tapestries, ropes, and car upholstery.Overtheyears,these tapestries and ropes were gradually replaced by synthetic polymers and, in the case of car upholstery, by polyurethane foam. Thus, not bringing economic and sustainable gains to the environment. Currently, according to Bonifácio (2019), coconut shell can be used as raw material for various production sectors, such as substrate for seedlings, and handicrafts, in addition to biomass for energy generation. The green coconut fiber used in this researchwasacquired to facilitate the assembly of the asphalt mixtures objectof research, in crushed form (powder) and the granulometric characterization was carried out to identify the best way to use it in the mixture with CAP 50 / 70. Figure 2 shows an image of the coconut fiber used.

Figure 2. Green coconut fiber used in the survey. Source: The authors (2020).

Conducting Tests on the Asphalt Binder CAP 50/70: After the characterization of the materials used in the Asphalt Mixture, studies were carried out seeking the inclusion of coconut fiber in the asphalt pavement. The methodology consisted of mixing green coconut fiber with CAP 50/70, varying the percentage by weight of the fiber and identifying the variations in the characteristics of the asphalt binder. Thus, using an Engineering Laboratory, located in the city of Olinda / PE, tests were carried out on samples of CAP 50/70 pure and others with 1%, 2% and 3% of green coconut fiber and the tests of Penetration, Viscosity and Softening Point, as recommended in the DNIT regulations. Table 2 shows the Standards / Test Methods that were followed to define the characteristics of the CAP 50/70 ligand. Figures 3 to 6 represent the performance of the Viscosity, Penetration and Softening Point tests.

Table 2. Ligand Testing Standards

Standard / Specification	Test
DNIT ME 004/1994	Saybolt viscosity –Furol
DNIT ME 131/2010	Softening Point
DNIT ME 155/2010	Penetration

Source: The authors (2020).

Choice of the percentage of addition of green coco fiber to be used in the Asphalt Mixture: After carrying out the tests varying the percentages, it was observed that the percentage of 3% addition of green coco fiber was the one that presented the best results, representingthe higher percentage of reuse among those studied which will bring greater environmental gains with the obtaining of this mixture.

Figure 3. Mixing CAP 50/70 with coconut fiber. Source: The authors (2020).

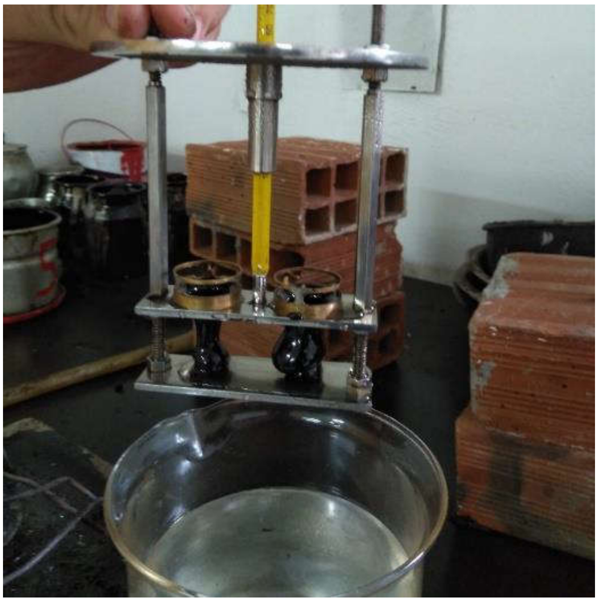

Figure 4. Viscosity test. Source: The authors (2020).

Figure 5. Softening Point Test. Source: The authors (2020).

Testing of Asphalt Mixtures: Thus, specimens were assembled to obtain asphalt mixtures with the materials presented in this research in pure form and with the addition of 3% coconut powder to the asphalt binder CAP 50/70, carrying out Marshall Stability tests to obtain Density, Voids, Empty Bitumen Ratio (RBV) and Stability. As well as the Diametral Tensile Strength Test. Cântabro wear tests were also carried out to measure the wear of pure asphalt mixtures and with the addition of green coconut fiber and ISA (Water Susceptibility Index) test to verify the behavior of the Mixtures under the action of water.

RESULTS AND DISCUSSION

Materials Characterization

***Granulometry Tests of Gravel 12 and 19*:** Granulometry tests were performed according to the Test Specification of DNIT (National Department of Terrestrial Infrastructure) number DNER-ME 083/98 Aggregates Granulometric Analysis that are presented in Table 3.

Table 3. Grain size of gravel 19 e 12

Sieves		Gravel 19		Gravel 12	
		Retained		Retained	
Pol	mm	(g)	(%)	(g)	(%)
1 ½”	32	0,00	0,00	0,00	0,00
1”	25	0,00	0,00	0,00	0,00
3/4"	19	120,19	8,00	0,00	0,00
1/2"	12,7	1.250,5	88,50	23,62	2,10
3/8”	9,5	154,48	98,80	359,66	34,70
N.4	4,8	12,06	99,60	693,53	97,60
N. 10	2	0,54	99,70	18,10	99,30
N. 40	0,42	0,51	99,70	1,36	99,40
N. 80	0,18	0,99	99,80	1,34	99,50
N. 200	0,075	1,50	99,90	2,11	99,70
PLATE		2,08	100,00	3,32	100,00
TOTALS		1.497,8		1.103,0	

Source: The Authors (2020).

Los Angeles abrasion: Second DNER-ME 035/98 Standard or Los Angeles abrasion test represents the wear suffered by the aggregate, when placed in the "Los Angeles" machine associated with an abrasive load, subjected to a determined number of revolutions of this machine at a speed of 30 rpm a Rotations per minute. Wear is expressed by the percentage, by weight, of the material that passes, after the test, through the 1.7 mm square mesh sieve (ABNT N.12).

Abrasion tests: Were carried out in Los Angeles, according to the DNER - ME 035/98 standard, both 19 mm and 12 mm gravel. Both times, the results of the wear tests were satisfactory, considering that the DNIT (National Department of Terrestrial Infrastructure) recommends the results of the Abrasion Los Angeles of the aggregates for use in asphalt mixtures with values below 50%.

Shape Index: According to the DNER ME 086/94 standard, the shape index represents the value of the diameter of the smallest circular sieve, specified, in which all the grains of a fraction pass, of which make up the chosen grade. For gravel 19 and 12, shape index tests were performed using the DNER-ME 086/94 Test Method, obtaining the results of 0.69 and 0.70, respectively. These results were satisfactory, since the DNIT (National Department of Terrestrial Infrastructure) specifies through DNIT Standard 031/2006 that the form indexes for CBUQ must be greater than 0.5.

Adhesiveness: Adhesion tests were performed to characterize the behavior of the aggregates when they are involved by the asphalt binder. According to DNIT ME 078/98, the adhesion of an aggregate to the bituminous material is the property that the aggregate must be adhered to by bituminous material. It is verified by the non-displacement of the bituminous film that covers the aggregate, when the aggregate-binder mixture is subjected, at 40°C, to the action of distilled water, for 72 hours. For samples of the 19mm and 12mm gravels studied here, the result found was satisfactory, and these aggregates can be used in the asphalt mixture. Table 4 presents a summary of the results obtained for gravel 12 and 19.

Table 4 - Abrasion Tests, Crush Form and Adhesion Index 19 and 12

Test	Gravel 19	Gravel 12
Los Angeles Abrasion (%)	29	28
Shape Index	0,69	0,70
Adhesiveness	Satisfactory	Satisfactory

Fonte: The Authors (2020).

Powder of Stone: For powder of stone, Granulometry and Fineness Module tests were carried out. For the Finance Module, a value of 5.8 was arrived at from the sum of retained values accumulated per 100 and for a granulometric analysis, the values presented in Table 5 are recorded.

Table 5. Granulometry

Sieves		Powder of Stone	
		Retained	
Pol	mm	(g)	(%)
1 ½"	32	0,00	0,00
1"	25	0,00	0,00
3/4"	19	0,00	0,00
1/2"	12,7	0,00	0,00
3/8"	9,5	0,00	0,00
N° 4	4,8	18,97	2,00
N° 10	2	283,06	32,30
N° 40	0,42	300,92	64,50
N° 80	0,18	139,07	79,30
N° 200	0,075	114,39	91,60
PLATE		78,86	100,00
TOTALS		935,27	

Source: The Authors (2020).

Sand: The sand used in the composition of the Asphalt Mixture was also studied through tests of Fineness Module and Sand Equivalent. The Fineness Module of the sand found was 4.7 in the same way as described for the stone powder. The Sand Equivalent, obtained through DNIT ME 054/97, was 78.8%. This value is above that specified in the DNIT ME 316/97 standard, which recommends a minimum value of 55%. For the granulometric analysis, the values shown in Table 6 were obtained.

Table 6. Sand granulometry

Sieves		Sand	
		Retained	
Pol	Mm	(g)	(%)
1 ½"	32	0,00	0,00
1"	25	0,00	0,00
3/4"	19	0,00	0,00
1/2"	12,7	0,00	0,00
3/8"	9,5	0,00	0,00
N° 4	4,8	7,49	1,00
N° 10	2	19,32	3,50
N° 40	0,42	408,24	56,10
N° 80	0,18	279,20	92,10
N° 200	0,075	54,55	99,20
PLATE		6,38	100,00
TOTALS		775,18	

Fonte: The authors (2020).

CAP 50/70 Asphalt Binder

Viscosity Tests: According to the Urban Cleaning Company of Recife (EMLURB, 2003) viscosity is the time in seconds that 60 mL of sample flow through the "Saybolt-Furol" orifice at a certain temperature. For these tests it was identified that the increase in the coconut fiber content incorporated to the binder also generates an increase in viscosity. As shown in the graph in Figure 6, the following results were obtained for pure mixtures with the addition of coconut fiber at a temperature of 165°C:

Pure = 79 seconds.
1% coco fiber = 101 seconds.
2% coco fiber = 115 seconds.
3% coco fiber = 125 seconds.

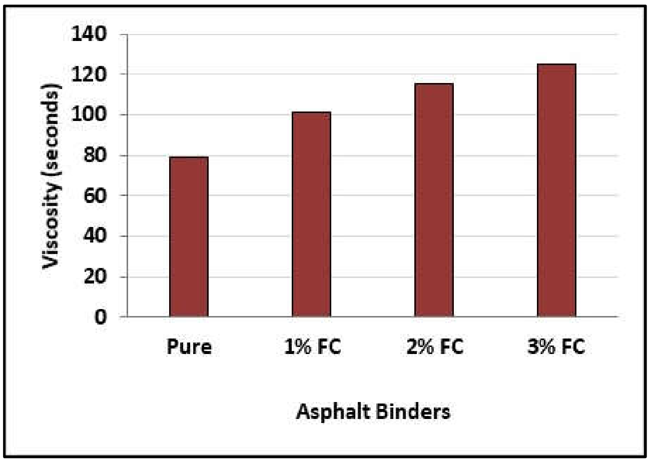

Figure 6. Viscosity test. Source: The Authors (2020)

This increase in viscosity allows an increase in the density of the mixture, generating denser samples, with less voids that tend to have asphalt mixtures more resistant to permanent deformations.

Penetration Tests: According to the DNIT ME 155/2010 standard, penetration represents the depth in tenths of millimeters, which a standard needle penetrates vertically into the material sample under preset load, time, and temperature conditions. This test determines the consistency of the asphalt binder at a temperature of 25°C. The results obtained as shown in Figure 7, showed that with the increase in the coconut fiber content incorporated into the binder, a decrease in the results of the penetration tests was observed.

Pure = 43µm.
1% coconut fiber = 41 µm.
2% coconut fiber = 35 µm.
3% coconut fiber = 32 µm.

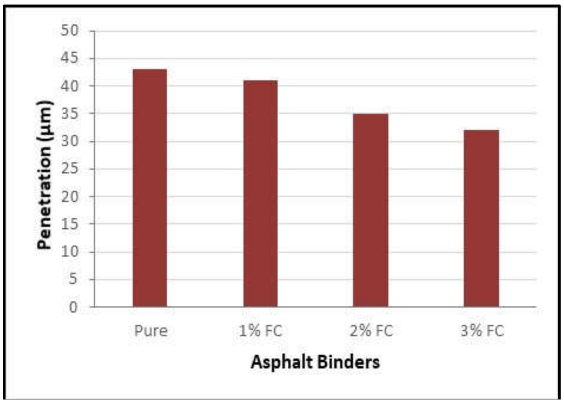

Figure 7. Penetration Test. Source: The Authors (2020).

Mohamed et al. (2018), studied the effect of glass fibers and cellulose on asphalt for concentrations in volume of 0.5%, 1.0% and 2.0% and found that the penetration value decreased with the addition of fibers glass and cellulose. The decrease in Penetration is an indication that the structured asphalt mixture with the modified binder will have good technical characteristics such as better resistance to permanent deformations.

Softening Point Tests: According to Standard ME 34/2003 of the Urban Maintenance and Cleaning Company of the City of Recife, Pernambuco, the softening point (ring and ball) is the temperature read at the moment when a standardized metallic sphere, crossing a standardized ring, perfectly filled with the bituminous material, it touches a reference plate after having traveled a distance of 25.4 mm under specified conditions. Thus, Softening Point tests were carried out using the Ring and Ball method on pure asphalt binders and with the addition of green coconut fiber. As shown in Figure 8, there was an increase in the Softening Point with the inclusion of Coconut Fiber. Highlight for the increase of 1°C in relation to the pure mixture for the binder with 3% of fiber. Values found for pure mixtures and with the addition of coconut fiber.

Pure = 55°C
1% coconut fiber = 54°C.
2% coconut fiber = 55°C.
3% coconut fiber = 56°C.

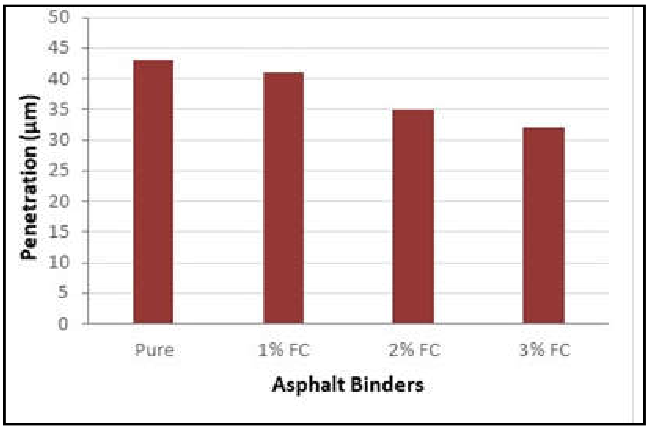

Figure 8. Penetration Test. Source: The Authors (2020).

It is noteworthy in the results found the increase of 1°C of the mixture with the addition of 3% of coconut fiber in relation to the pure mixture. This increase represents a better behavior regarding deformations and high temperatures of the mixture with addition of fiber. According to Azevedo at al. (2019), it is important to take into account that a high amount of fibers introduced in the asphalt binder can bring a fragile mixture with little workability, which can hinder the process of assembling the mixture. Thus, it is important for each type of fiber to be used as an additive to the asphalt binder to define a percentage that meets the normative parameters and that seeks the best use condition. In this research, the percentages of 1%, 2% and 3% by weight were adopted for the addition of green coconut fiber due to the success in other studies carried out using smaller percentages such as Vale (2007), which studied SMA-type asphalt mixtures with addition of 0.1% to 0.7% of coconut fiber to the binder adopting 0.5% for the assembly of mixtures type SMA and Panda (2013), added 0.3% of coconut fiber in asphalt mixtures type SMA and obtained good results for the technical characteristics of this mixture.

Asphalt Mixtures: After carrying out the Viscosity, Penetration and Softening Point tests on Asphalt Binders with and without the addition of green coconut fiber. It was chosen to perform the molding of the specimens the percentage of 3% addition of green coconut fiber, due to this percentage having presented the best results in the tests with the asphalt binder CAP 50/70 and being the percentage of greatest reuse among those studied.

Molding of Specimens: Thus, specimens were molded with the percentage of 3% green coconut fiber in the asphalt binder and specimens without the presence of green coconut fiber, as shown as Figures 9 and 10.

Stability: Stability tests were performed according to Figure 11 where the results found showed a decrease in the stability of the asphalt mixture with the addition of 3% of the coconut fiber in relation to the pure mixture, but the value of 1.073Kgf found for the fiber sample meets the DNIT standards and reference parameters, representing more than twice the minimum requested value, as shown in Tables 7 and 8, and Figure 12.

Figure 9. Preparation of Asphalt Mixtures. Source: The Authors (2020)

Figure 10. Compaction of the Specimens. Source: The Authors (2020)

Figure 11. Marshall test run. Source: The Authors (2020)

Tables 7. Results Stability Tests

Asphalt Mix	CP1 (Kgf)	CP2 (Kgf)	Average (Kgf)
Pure	1328	1288	1308
3% Coco Fiber	1057	1090	1073

Source: The Authors (2020).

Table 8. DNIT Reference Values – Stability

Features	Test Method	Rolling Layer	Binding Layer (Binder)
Percentage of Voids %	DNER – ME 043	3 a 5	4 a 6
Bitumen and voids ratio	DNER – ME 043	75 - 82	65 – 72
Minimum Stability (Kgf) (75 strokes)	DNER – ME 043	500	500
Tensile Strength by Static Diametral Compression at Min 25ºC, MPa	DNER – ME 136	0,65	0,65

Source: DNIT (2004)

Table 9. Fluency Results

Asphalt Mix	CP1 (mm)	CP2 (mm)	Average (mm)
Pure	3,10	3,00	3,10
3% Coconut Fiber	2,50	2,60	2,60

Source: The Authors (2020).

Table 10. DNIT Reference Values – Fluency

Test	Test Method
Bitumen and voids ratio (%)	75 – 82
Stability (Kgf)	>500Kgf
Diametral Compression Tensile (Kgf / m^2)	> 0,65 MPa
Fluency (mm)	2,0 a 4,5

Source: The Authors (2020)

Table 11. Tensile Strength Results

Asphalt Mix	CP1 (MPa)	CP2 (MPa)	Average (MPa)
Pure	1,25	1,26	1,25
3% Coco Fiber	1,06	1,04	1,05

Table 12. DNIT Reference Values - Tensile Strength

Test	Test Method
Bitumen and voids ratio (%)	75 – 82
Stability (Kgf)	>500Kgf
Diametral Compression Tensile (Kgf / m^2)	> 0,65 MPa
Fluency (mm)	2,0 a 4,5

Source: DNIT (2004)

Fluency: The mixture with the presence of coconut fiber showed a decrease in the creep values of the samples, but it met the interval recommended by the Standards, as shown in Tables 9 and 10.

Tensile Strength: Diametral Tensile Strength tests were performed according to Figure 12 where the mixture with the addition of coconut fiber showed a decrease in the Tensile Strength values, presenting a more fragile mixture with respect to this property. However, the values found are above the minimum recommended by the Standards. As shown in Tables 11 and 12. Oda (2011), analyzed the use of several types of fiber in SMA asphalt mixtures and used good results for Tensile Strength using 0.5% green coconut fiber, 0.5% cellulose, 0.5% sisal and 0.5% polyester and approved, as shown in Table 13, with a change in the type of fiber and results in resistance to changes that are not very variable.

Figure 12. Diametral Tensile Strength Test. Source: The Authors (2020).

All fibers showed results of Tensile Strength close to 1.00 MPa, the same value found in this research using 3% addition of Green Coconut Fiber.

Table 13. Results of other research Tensile Strength

SMA Mixture	Tensile Strength (MPa)
AC 50–70, with cellulose fiber	1,1
AC 50–70, with coconut fiber	1,1
AC 50–70, with sisal fiber	1,0
AC 50–70, with polyester fiber	0,8

Source: The Authors (2020).

Cânabro Wear: The mixture with the addition of coconut fiber showed lower wear results than the pure mixture, thus presenting a dense and more resistant to wear, as shown in Table 14.

Table 14. Results Cântabro Wear

Asphalt Mix	Initial Weight (g)	Final Weight (g)	Wear (%)
Pure	1.202,50	1.164,31	3,20
3% Coconut Fiber	1.202,27	1.177,80	2,03

Source: The Authors (2020).

Water Susceptibility Index (ISA): The mixture with the addition of coconut fiber showed results of water susceptibility index higher than the pure mixture, which characterized that the mixture with addition of fiber presents a better behavior than the pure one when submitted to the action of water, as shown in Table 15.

Table 15. Water Susceptibility Index Results

Asphalt Mix	Initial Reading (g)	Final Reading (g)	ISA (%)
Pure	560,00	496,00	88,57
3% Coconut Fiber	560,00	594,00	94,27

Source: The Authors (2020).

FINAL CONSIDERATIONS

The presence of coco fiber contributed to the increase in resistance to permanent deformation, identified by the reduction in penetration results and increased consistency. The increase in the softening point was also a positive aspect for the technical characteristics of the binder, as this increase tends to bring greater resistance to high temperatures for asphalt mixtures and consequently more resistance to aging. Regarding the mechanical characteristics of the mixture, a decrease in stability, creep and tensile strength was observed in the mixture with the addition of 3% of the coconut fiber. However, the values found are within the limits required by the standards. In the cannabinoid wear test, the results of Mixing with 3% coconut fiber were better than pure. The sample with the presence of 3% of coconut fiber showed less wear when subjected to the action of water in relation to pure mixture, these results represented a better behavior of the sample with coconut fiber in relation to pure considering the Susceptibility to water. The analysis of all the results obtained in pure asphalt mixtures and with the addition of coconut fiber revealed that the mixtures with the addition of coconut fiber lost some quality in relation to some parameters such as stability and tensile strength, but their results met the standards. As for the Cânntabro Wear and Susceptibility to water the samples with coconut fiber presented results even better than the pure mixtures. Thus, this research concluded that the application of addition of coconut fiber in the amount of 3% by weight adding to the binder CAP 50/70 is viable in asphalt mixtures considering the materials used in the pavements in Recife / PE.

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