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Evaluation of the Effect of Camu Camu Peel on the Physical Properties of Asphalt Cement

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Abstract **-** Oxidation in flexible pavements is a recurring issue in road engineering, primarily caused by moisture, temperature, and climatic conditions. This damage is observed globally, significantly affecting Europe with its low temperatures and the Americas with high temperatures, where some countries report up to 50% of their pavement deteriorated due to oxidation. A solution to this problem is the use of natural modifiers, which enhance the properties of asphalt cement, such as rice husk and blueberry fiber.

This study evaluates the effect of Camu Camu peel (FCC), scientifically known as *Myrciaria dubia*, as an antioxidant additive on the physical properties of 60/70 asphalt cement. As one of Peru's richest fruits in antioxidants, thanks to its phenolic compounds, Camu Camu helps protect pavements exposed to various temperature conditions against aging. FCC was processed into a fine powder and incorporated in proportions of 2%, 5%, and 10% into asphalt mixtures, which were then subjected to penetration, ductility, and softening point tests before and after accelerated aging.

The results indicate significant improvements in the physical properties and oxidation resistance of asphalt cement. The addition of 10% FCC increases ductility by 25%, improves penetration resistance by 28%, and raises the softening point by 26% after aging. Furthermore, the susceptibility to oxidation progressively decreases, highlighting an increase in the material's durability and functionality.

Keywords**:** Camu Camu, phenolic compounds, modifier, antioxidant, Myrciaria dubia, asphalt cement

1. Introduction

It Asphalt has been used for many years as the main binder in pavement construction worldwide. Therefore, a high demand for asphalt is predicted in the coming years [1]. As it is known, it is derived from petroleum, which is a non-renewable energy source, thus being an unsustainable solution. Therefore, in recent years, sustainable development for a circular economy has become an important development goal of the world [2]. As environmental awareness improves, people have realized that the trend of road construction should be transformed towards sustainable forms and materials [3]. Asphalt cement as we know is used in road construction due to good performance [4]. Therefore, solving problems such as aging and oxidation are significant in road engineering, especially in regions with extreme climates. These processes cause hardening of the material and the appearance of cracks, potholes and loss of adhesion, affecting the durability and functionality of roads [5]. In a world where roads are exposed to thermal variations and intense UV radiation, oxidation represents a constant challenge to maintaining road infrastructure, increasing repair costs and affecting the safety of users.

Similarly, recent studies show that asphalt presents a notable improvement in its physical properties by containing natural modifiers. On the one hand, rice husk (RHA) contains approximately 20% lignin in its composition [6], which contributes to increasing the resistance to moisture and the stiffness of the asphalt [7]. Likewise, bamboo fiber (BAM) improves the performance of asphalt against fatigue [8], it also optimizes shear strength at high temperatures and flexibility at low temperatures [9]. In addition, it has been proven that the addition of grape pomace to the asphalt mixture improves the durability and long-term performance of the pavement [10]. On the other hand, blueberry, when applied at 6% in the asphalt mixture, contributes to increasing the stiffness, reducing the thermal susceptibility, improving the elastic properties and increasing the resistance to deformation of the asphalt [11].

On the other hand, studies indicate that camu camu peel and seeds contain a significant amount of phenolic compounds, reaching up to 60 mg per 100 g of peel in its ripe state, and its concentration increases as the fruit ripens [12], the phenolic compounds present in camu camu peel include flavonoids and anthocyanins, which are plant pigments responsible for the characteristic red, purple and blue colors of many fruits. These compounds have been shown to have protective effects against oxidative aging [13].

For the above reasons, the present investigation aims to evaluate the effect of camu camu shell (FCC) on the physical properties of asphalt cement. By incorporating different proportions of camu camu powder in the asphalt mixture, the aim is to determine its potential as an antioxidant additive to improve pavements in areas with temperature variations.

2. Materials and Mixture Preparation

2.1. Materials

Asphalt cement grade 60/70 (AC) was selected for the evaluation. Table I shows the basic properties of AC.

Table 1: Physical properties of bitumen 60/70

Property/Unit	Test method	Specification
Penetration at 25°C (0.1 mm)	AASHTO T 49	60-70
Softening Point (°C)	AASHTO T 53	46-54
Ductility at 28°C (cm)	AASHTO T 51	Minimum 100
Flash Point (°C)	AASHTO T 48	Minimum 230

Camu camu peels (FCC) are collected from waste provided by different companies that are responsible for manufacturing and exporting products from the pulp of said fruit.

They are then washed to remove any possible contaminants. They are then dehydrated in an oven at 60°C± 5°C for 12 hours, the time being determined by a previous study [14]. Once this process is finished, the shells are crushed and sifted and then passed through the ASTM N°100 mesh to obtain a fine powder.

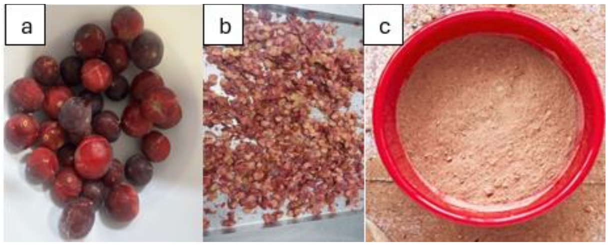

Fig. 1: (a) Camu camu; (b) Dehydrated shell; (c) FCC powder

2.2. Preparation of modified CA samples

First, the asphalt mixture is heated to temperatures between 150°C and 180°C. Then, the FCC powder is added and mixed using a mechanical stirrer at 500 rpm to ensure complete dispersion of the additive. The mixing process was carried out at a constant temperature of 150°C for 30 minutes until a homogeneous mixture was obtained. Different samples were prepared with 2%, 5% and 10% FCC content by weight (w/w). Additionally, to evaluate the effects of oxidation on the samples, two aging states were considered: initial and short-term aging.

Fig. 2: Asphalt mix

3. Methods and tests

This research is quantitative in nature, as it is sequential and probative. It is also exploratory in nature because it addresses a novel area in the field of asphalt modification.

The tests for the physical characterization of the unmodified and modified asphalt cement were evaluated with the following tests, softening point is an indicator of the tendency of asphalt cement to flow at high temperatures during its service life, ductility is used to evaluate the capacity of a material to deform plastically before fracturing [15] and penetration which measures the resistance or ease with which a material allows an object, such as a penetrometer or a cone, to penetrate its surface under controlled conditions [10], according to ASTM D36, ASTM D113, ASTM D5 standards, respectively. Likewise, the accelerated aging method (RTFOT) was applied to simulate the short-term aging of the samples according to ASTM D2872. This method consisted of each 35 g sample being subjected to the effects of heat and air flow at 400 ml/min for 85 minutes at a temperature of 163°C at a rotation speed of 15 rpm.

The susceptibility to oxidation of the FCC asphalt samples was evaluated with the softening point index (SPI). In equation 1

$$SPI = \frac{RFTO\ SP\ -\ Before\ aging\ SP}{Before\ aging\ SP} \tag{1}$$

The oxidation index was determined based on equation 2 which uses the penetration index.

$$PI = \frac{1952 - 500logpen - 20SP}{50logpen - SP - 120} \tag{2}$$

Where:
Pen: Penetration value at 25°C
SP: Softening point
This allows the oxidation resistance of the FCC modified asphalt mixture to be evaluated.

4. Results and discussion

Table 2: Abbreviation to recognize the type of asphalt

Type of Asphalt	ABBREVIATION
Asphalt 60-70	AC
Asphalt 60-70 modified with FCC al 2% with respect to the weight	2% FCC
Asphalt 60-70 modified with FCC al 5% with respect to the weight	5% FCC

Asphalt 60-70 modified with FCC al 10% with respect to the weight	10 % FCC

The data in Table 2 show the types of modified asphalt with their percentage by weight. Also, on the side you can see the abbreviation with which the samples were identified to avoid confusion.

Table 3: Physical properties of modified bitumen 60/70

Property/ Unit	**Binder Type**			
	Bitumen 60-70	**2%**	**5%**	**10%**
Penetration at 25°C (0.1 mm)	82	75	69	59
Softening Point (°C)	45	48	51.5	54
Ductility at 28°C (cm)	100	105	113	125
PI	-1.372	-0.7336	-0.0324	0.157
After RTFOT				
Penetration at 25°C (0.1 mm)	47	43	39	36
Softening Point (°C)	50	55	59	63
PI	-0.8592	-0.3779	0.2366	0.819
SPI	0.1111	0.1458	0.1456	0.1667

The data in Table 3 show the results of the penetration, softening point and ductility tests. These were carried out at two times, before and after aging. With these results, the oxidation indices can be obtained, which indicate how much the modified sample improves compared to the virgin sample. The results show that the modification of the mixture with FCC enhances its physical properties, which in turn are indicative of helping to control the oxidation of the asphalt mixture with respect to the aging time.

4.1. Ductility results

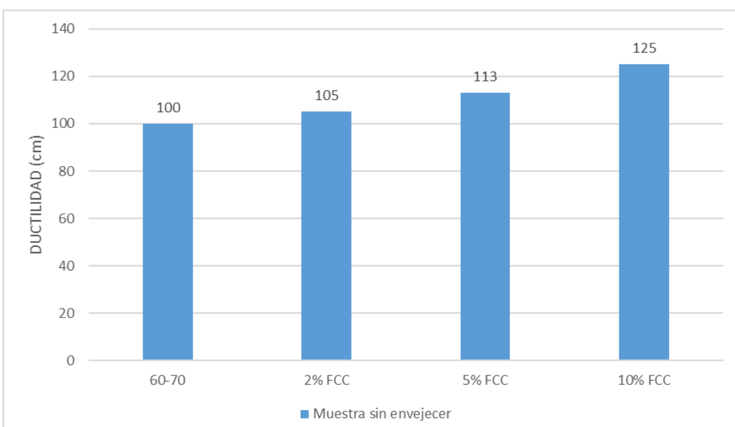

Fig. 3: Ductility test results of the sample

In Fig. 3, the results of the ductility tests performed on the 4 samples made for the investigation are observed. In the case of the sample that has not been modified, a ductility of 100 cm is recorded, while in those modified with 2%, 5%, 10%, with respect to the mixture, the results of 105, 113 and 125, respectively, are recorded. In this property, it can be verified that the increase in ductility goes progressively with the increase in the FCC modifier. According to Fig. 3, the mixture that has been modified with 10% of its weight shows the highest increase in ductility, it is enhanced by 25% with respect to the virgin sample, while when modified with 2% and 5% it is only improved by 5% and 13%, respectively. This result demonstrates that, when the mixture is modified with FCC, it becomes more fluid.

4.2. Penetration results

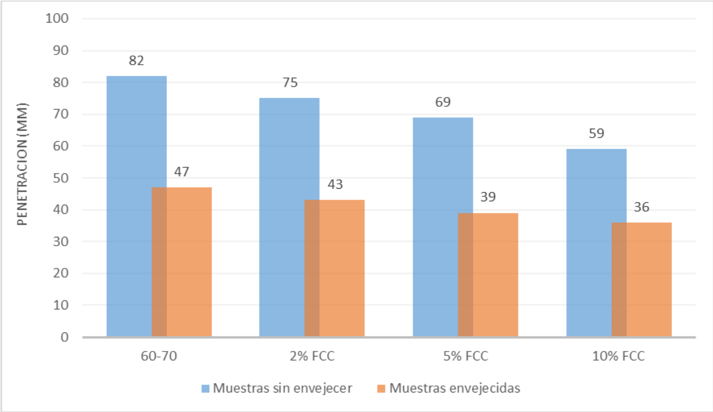

Fig. 4: Penetration results of the sample before and after the aging

Fig. 4 shows the results of the penetration test in millimeters performed on the mixtures before and after the RTFOT aging test. In this test, the results reflect how much a mixture is penetrated after the same force is applied. According to Fig. 4, the modified mixtures increase their resistance to penetration by 8.5%, 15.85% and 28% when they are modified at 2%, 5% and 10% of the weight of the mixture, respectively. Likewise, Fig. 4 verifies that after the RTFOT test, the resistance to penetration decreases by 8.5%, 17.02% and 23.4% when they are modified in 2%, 5% and 10% of the weight of the mixture, respectively, to demonstrate that, even after aging, the modified samples continue to enhance the property of resistance to penetration. It can also be deduced from Fig. that the mixture modified at 10% with FCC is the one that improved the most in this physical property, it reaches an improvement of 28% with respect to the unaged virgin mixture and 3.4% with respect to the aged virgin mixture.

4.3. Softening Point results

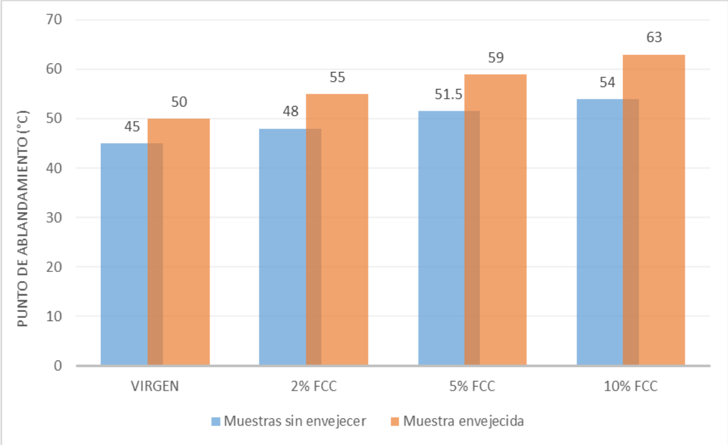

Fig. 5: Softening point results of the sample before and after aging

The results of the softening point test are shown in Fig. 5. The results of the 60-70 sample and those modified at 2%, 5% and 10% with respect to the weight of the unaged mixture can be identified as 45, 48, 51.5 and 54 °C, respectively. In addition, it can be seen that after aging these increase to 50, 55, 59 and 63 °C, this shows that having more FCC content the softening point increases progressively. After the above said, it can be said that the asphalt mixture when modified at 10% with respect to its weight is improved by 20% with respect to the unaged virgin mixture, on the other hand, when aged it shows an improvement of 26% with respect to the virgin sample. Furthermore, in Fig. 5 it can be observed that when modified with FCC from 5% of the mixture weight, this shows a significant improvement in the softening point property, this improves by 14% before aging and almost 20% after being aged. With the results shown in Fig. 5 it can be said that the FCC significantly enhances the asphalt mixture in the softening point property, this makes it more resistant to oxidation at high temperatures.

4.4. Oxidation indices

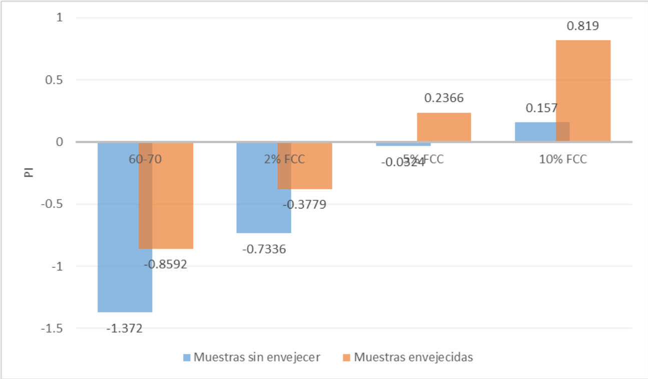

Fig. 6: Results of the Oxidation Index of the mixtures

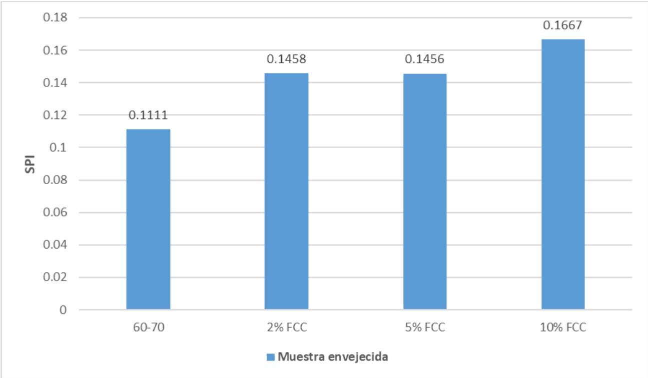

Fig. 7: Softening Point Index Results Mixtures

The results shown in Fig. 6 represent the oxidation index of the modified and unmodified mixtures, as can be seen, the 60-70 mixture has a negative oxidation index, which means that being a virgin mixture it is highly susceptible to oxidation both when not aged and when aged; likewise, when the mixture is modified with 2% FCC the oxidation index is still low, which shows that although it has improved by 46.5% and 56% with respect to the unaged and aged virgin mixture, respectively, this modified mixture is still susceptible to oxidation; On the other hand, when the mixture is modified with 5% FCC, the oxidation index still reflects an interesting variation for the research, which shows that before aging the mixture improves by 97% and 127% with respect to the aged mixture, it can be verified that by modifying it with 5% FCC the mixture begins to significantly improve the oxidation index, which means that it is at this percentage where the modifier begins to act potentially in the mixture, finally, the results of the mixture when modified with 10% FCC show significant improvement both without aging and aged, this improves by almost 200% with respect to the virgin mixture, with this it can be said that the FCC reduces the oxidation index, therefore making it less susceptible to oxidation with respect to time and temperature.

In Fig. 7, the results of the oxidation point index are observed, where the percentage in which the mixture varies before being aged and after aging is verified. For asphalt 60-70, the result of 0.1111 is shown, this means that after aging its softening point increased by 11.11%, in the case of asphalt with 2% FCC it is observed that at the end of the aging the softening point increases by 14.58%, which shows that in addition to having a higher softening point than virgin asphalt, this over time its increase behavior is greater; on the other hand, when the asphalt is modified with 5% FCC the softening point index decreases slightly with respect to asphalt modified with 2% FCC, this bridge shows an increase of 14.56%, it is also a quite considerable increase with respect to virgin asphalt, finally in the case of the softening point index of asphalt modified with 10% FCC a considerable increase is shown with respect to other asphalt because, apart from having a higher softening point, the increase with respect to time is 16.67%.

5. Conclusion

After modifying the asphalt with Camu Camu fiber, the effects it has on its physical properties were evaluated. After the tests carried out and the results obtained, it can be concluded that:

1. It can be concluded that FCC helps to increase the ductility property of asphalt, since the test shows that with the added modifier it ir more fluid, according to the results obtained, its ductility can increase by up to 25%.
2. For the softening point property, it is concluded that the FCC shows that it is an enhancer for this property, since after being aged it shows a 26% increase in the softening point. In the same way, in relation to its own increase, it has a variation of 16% with respect to time, which is considerably greater than the 11.11% that is recorded with virgin asphalt.
3. In the penetration resistance property, it is shown that FCC is a very good enhancer. The virgin sample records a penetration of 82 mm before aging and 47 mm after aging, then when modified, a decrease in penetration of 24.3% is achieved compared to virgin asphalt, this shows that it helps resistance to penetration.
4. After performing the calculations of the oxidation indices, it is concluded that starting with the addition of 5% FCC, a decrease in the susceptibility to oxidation can be seen. It was also demonstrated that FCC significantly reduces the effect of oxidation on asphalt.
5. It is concluded in this research that the addition that obtained the best results is adding the FCC to 10% of the weight of asphalt mixture, since in ductility it gives an improvement of 25%, while in the penetration resistance is improved by 28% and 24.3%, before and after being modified, respectively. On the other hand, in the softening point test it also shows the highest improvement in the research, therefore the susceptibility to oxidation is the lowest

6. Recommendations

The work mainly investigated the evaluation of the potential of FCC as an antioxidant additive to improve pavements, through physical characterization tests.

However, more points are desired to be investigated in the future. Firstly, it is possible to analyse from what percentage of additive use the improvement curve begins to decrease, damaging the softening point, ductility and penetration. Secondly, the influence of the type of cooling of the asphalt mixture with additive and if this generates any change in the properties, improving or reducing its useful lifetime; for this, not only the physical properties of the pavement could be analysed but also the rheological ones.

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