Evaluation of indirect tensile strength and stability of fiber-reinforced cold asphalt mixes

Evaluación de la resistencia a la tracción indirecta y estabilidad de mezclas asfálticas en frío reforzadas con fibras

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Abstract

The development of a country depends directly on the number of roads it has, with the pavement being a fundamental piece to a large extent. This research aims to evaluate the behavior of the index properties and tensile strength of cold mixtures and reinforce them with synthetic fibers. The use of alternative materials from polymers has become an alternative in the manufacture of asphalt mixtures as a modifying or reinforcing agent. The mixtures were designed following the provisions of the Hubbard-Field method (sand-asphalt). The results of this research show that for low percentages of microfiber (0.05 and 0.10%) replacing the stone aggregate, the index properties of the mixtures and the tensile strength suffer a considerable deterioration compared to the standard mixture, although these values are within the limits required by regulations. For 0.15% the microfiber, improvement was observed compared to the other percentages, but this research does not have enough data to ensure its use, so percentages higher than 0.15% microfiber must be evaluated.

Keywords: cold mix, modified mix, microfiber, index properties, tensile strength.

Resumen

El desarrollo de un país depende directamente de la cantidad de vías que este tenga, siendo el pavimento una pieza fundamental en gran medida. Esta investigación plantea evaluar el comportamiento de las propiedades índices y la resistencia a la tracción de las mezclas en frio reforzarlas con fibras sintéticas. El uso de materiales alternativos provenientes de los polímeros se ha convertido en una alternativa en la fabricación de mezclas asfálticas como agente modificador o de refuerzo. Las mezclas se diseñaron siguiendo lo establecido en el método Hubbard-Field (arena-asfalto). Los resultados de esta investigación muestran que para porcentajes bajos de microfibra (0,05 y 0,10 %) en sustitución del agregado pétreo, las propiedades índices de las mezclas y la resistencia a la tracción sufren una desmejora considerable en comparación con la mezcla patrón, aunque estos valores se encuentren entre los límites exigidos por la normativa. Para el 0,15 % de microfibra, se observó mejora en comparación con los otros porcentajes, pero esta investigación no tiene suficientes datos para asegurar su uso, por lo que se deben evaluar porcentajes superiores al 0,15 % de microfibra.

Palabras clave: Mezcla en frío, Mezcla modificada, Microfibra, Propiedades índice, Resistencia a la tracción.

1 Introduction

The present research refers to the design of cold asphalt mixtures reinforced with commercial brand polypropylene synthetic microfiber (SikaFiber®-6), which reduces the appearance of cracks, composed of monofilaments that during mixing distribute randomly to form a uniform three-dimensional network. The incorporation of the microfiber into the asphalt mixture will be carried out dryly. The stability and tensile strength of this mixture were evaluated through laboratory tests that characterize the mechanical resistance and deformation of the pavement.

Among the main characteristics of this type of mixture is that it is placed and compacted at room temperature. On the other hand, they imply savings in energy consumption as well as a reduction in the generation of toxic vapors and dusts.

Depending on the conditions of the foundation material, pavement structure, traffic, stability and deformation of the mixture, cracks produced by tensile stress may occur. For some time now, modified asphalt mixtures have been developed both hot and cold, with different types of polymers to improve their index properties (Gavino (2022), Gamboa (2021), Briceño and González (2016), in these previous investigations the use of different types of polymers has been demonstrated, of different shapes and mixing methods; have demonstrated improvements or at least ranges within specifications.

The presence of traction cracks in the pavement allows the passage of water that oxidizes the asphalt, causing the mixture to come loose and deteriorate the structure. For this reason, the idea of adding microfibers was born to generate a contribution of tensile strength and properties that increase its durability, in cold and hot mixtures (Adrianzen et al. (2022), Cárdenas (2021), Agathon et al. (2020), Park et al. (2020), Al – Bdairi (2020), Mohamed et al. (2020), Shanbara et al. (2020), Tien et al. (2020), Javani, Kashi and Mohamadi (2019), Mardones et al. (2018), Preciado et al. (2017)). Furthermore, in this research it was verified whether these filaments considered anti-cracking can really exert a transformation in the tensile strength and index properties of cold asphalt mixtures.

Asphalt mixtures with binding material, fast curing liquid asphalt (RC-250) Venezuelan standard COVENIN 1471:1993 (COVENIN, 1993) and unprocessed aggregates of natural origin were tested, where a series of tests were carried out applied to the briquettes. It began with the design of a standard cold asphalt mixture, using the Hubbard-Field method for the preparation of briquettes and searching for the optimal percentage of RC-250 for the best behavior in the different proportions of aggregate and asphalt, subjecting the mixture to unfavorable conditions. Then indirect tensile and stability tests were carried out. Subsequently, with this optimal percentage of RC-250, different percentages of microfiber incorporated into the mixture were added, executing the same tests carried out previously and finding the appropriate percentage of microfiber in the mixture.

The purpose of this research work was to determine the behavior of a cold asphalt mixture reinforced with synthetic polypropylene microfiber, designed according to the requirements of the Venezuelan standard COVENIN 2000:1987 (COVENIN, 1987) using the Hubbard-Field method (1925).

2 Methodology

The research was based on the Hubbard-Field (sand-asphalt) method for the design of cold asphalt mixtures. As a first stage, a standard mixture with optimal RC-250 content was designed, evaluating compaction, voids, absorption, stability and indirect traction tests; An analysis of the data obtained was carried out to meet a series of objectives set by the research. Volumetrically corrected percentages of microfiber as reinforcement were then added to the standard mixture to determine its index properties and tensile strength. To finally compare the results obtained experimentally and establish a series of recommendations.

In this order of ideas, each of the steps to achieve the stated objectives is described.

2.1 Cold asphalt mix design, Hubbard-Field Method (sand-asphalt), standard mix

Characteristics of stone aggregates

The material to be used was selected, in this case it was a silty gravel free of impurities or organic waste acceptable for the design, this loan is located in the town of Mucuchies state of Mérida, on the road that leads to the town of Gavidia, this area of the central region of the Venezuelan Andes is part of the Mucuchies formation, this unit outcrops north of the Chama River, its lithology is recognizable by coarse and fine grained sandstones, deposited during the Late Miocene-Pliocene in alluvial plain environments.

According to the method, the aggregates must have the following characteristics: the percentage of material passing the #200 sieve must be less than 25 %, the sand equivalent must be greater than 25 % and a plasticity index no greater than 6. The chosen material is sifted until leaving the pass of sieve #4. Once the aggregates have been analyzed and their possibilities of use accepted, the corresponding design was carried out.

The granulometric test of the aggregates was carried out under the ASTM D422 method (ASTM, 1998), the Consistency Limits under the ASTM D4318 method (ASTM, 1983); and was classified using the Unified Soil Classification System (SUCS) (ASTM, 1985).

Approximate determination of the percentage of asphalt

Once the granulometry and specific weight of the aggregate were known, it was mixed with different quantities of liquid asphalt. To do this, the quantity required to obtain a mixture of optimal quality must be known approximately. This was obtained by trial and error and/or by applying Equation 1, as in this case.

$P = 0{,}02a + 0{,}045b + 0{,}18c$ ………Equation (1)

Where:
P: Approximate percentage of asphalt; a: Percentage of aggregate retained on the #10 sieve; b: Percentage of aggregate passing through the #10 sieve and retained on the #200 sieve and c: Percentage of aggregate passing through the #200 sieve.

Once the value of P was known, briquettes were made with percentages of asphalt below and above this value.

Sample preparation 1,500 g of sand previously oven-dried at 110 °C for 24 hours were taken to prepare each briquette. The RC-250 was then heated to approximately 45 °C by mixing it with the aggregate. Figure 1 shows this process.

Fig. 1. Weighing of aggregate plus percentage of RC-250 asphalt for briquetting.

Mixing was completed when the asphalt covered the entire aggregate; the same procedure was followed for the other mixtures.

Curing of the mixtures

The mixtures were cured at room temperature for 24 hours, as shown in Figure 2.

Fig. 2. Curing of the mixtures.

Briquette compaction

Then the amount of aggregate and RC-250 was weighed to achieve mixtures with different percentages of asphalt to carry out the necessary tests and determine the optimal percentage of the same. This weighing is shown in Table 1. To compact the mixture, it was placed in the 2-inch diameter mold to produce a 1-inch-high briquette, as shown in Figure 3

Table 1. Weighing of aggregates and % RC-250 to be evaluated.

Asphalt RC-250 (%)	Mixture weight of aggregate + Asphalt (g)
5.00	104.00
6.00	106.00
7.00	108.00
8.00	110.00
9.00	112.00
10.00	114.00
12.00	115.00
13.00	115.00

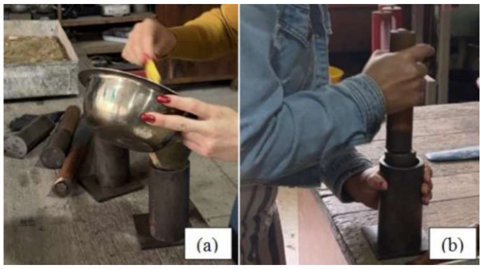

Fig. 3. Placing the sample in the compaction mold.

The compaction of these briquettes was carried out in three stages; the first of them with hammer No. 1 with a rectangular surface and weighing 1100 grams, with which it was hit 25 times to accommodate the mixture in the mold. The second stage consisted of giving 20 blows with hammer No. 2 of the same weight as No. 1 and with a circular face. The third stage was with static compaction applying a load of 9425 lb (4275 Kg) equivalent to 3000 lb/in2 (211 Kg/cm2) for a time of 2 minutes. As shown in Figure 4.


Fig. 4. Process and compaction stage of the sample placed in the 2 inch diameter mold for briquette manufacturing.

The briquettes once removed from the mold were measured to guarantee a height of 2.54 cm (1 inch), according to the requirements of the applied method. If the briquette height is outside this value, the height must be adjusted as follows:

Adjusted mix weight= $\frac{2{,}54 \text{ x (weight } \textit{of heavy mixture})}{\textit{briquette height}}$…………………………………………………………...…. Equation (2)

Once all the briquettes are finished, they are left in the air at room temperature for 24 hours and then tested. As shown in Figure 5.


Fig. 5. Manufactured briquettes (42 briquettes) for testing.

The number of briquettes produced for each stipulated percentage of RC-250 were: 2 briquettes for air stability, 2 briquettes for stability after 1 hour in water at 60 °C, 2 briquettes for absorption, swelling and stability test after 72 hours of partial immersion in water at room temperature.
In addition, the following were determined: real density, theoretical density, compaction percentage, voids percentage and adhesion.
The briquettes of each percentage of RC-250 intended for the stability test are immersed in water at room temperature for 72 hours.
The heights and diameters were weighed and measured before and after the aforementioned immersion, thus obtaining an initial and final weight, height and diameter. As recommended by the method, the exact measurement location is marked to then make the final measurement and thus have a better relationship.

Calculations

The percentages of absorption, swelling and real density were calculated using the following equations:

% Absorption= $\frac{\mathrm{Pf-Pi}}{\mathrm{Pi}}\mathrm{x}100$ …………Equation (3)

% Swelling= $\frac{\mathrm{Vf-Vi}}{\mathrm{Vi}}\mathrm{x}100$ ………..…Equation (4)

$\mathrm{R.D} = \frac{\mathrm{Pi}}{\mathrm{Vi}}$……………………………. Equation (5)

$\mathrm{T.D.} = \frac{100}{\frac{\mathrm{W1}}{\mathrm{G1}}+\frac{\mathrm{W2}}{\mathrm{G2}}+\frac{\mathrm{W3}}{\mathrm{G3}}}$…………….……….. Equation (6)

Where:
Pf: Final weight; Pi: Initial weight; Vf: Final volume; Vi: Initial volume; R.D: Real density; T.D: Theoretical density; W1: Percentage of aggregate used; W2: Percentage of asphalt cement; W3: Percentage of hydrocarbon volatiles; G1, G2, G3: Respective specific weights.

Once the Real Density and Theoretical Density are known, the percentages of compaction and voids are calculated with the following equations:

%Compaction=(R.D)/(T.D)x100 …...Equation (7)

%Voids=100-%compaction ……….. Equation (8)

Stability test

After having immersed the briquettes to be tested in water at 60 °C for one hour, they were removed and dried superficially to proceed to place the briquette in the loading machine. The test load is then applied at a constant strain of 51 mm (5”) per minute, until failure. The failure point is defined by the maximum load reading obtained. The total number in pounds required for briquette failure to occur was recorded as the stability value.

Additionally, the same test was carried out for briquettes in non-submerged condition and in a constant temperature condition taken to the oven.

Finally, once all the tests have been carried out, an analysis of the results is carried out as a whole to issue the corresponding recommendations; This analysis is done based on the index properties.

The curves corresponding to the Asphalt-Stability relationships (air stability, 3 days of partial immersion, at 60 °C dry and 60 °C wet) are graphed separately. Asphalt-Adsorption, Asphalt-Swelling, Asphalt-Voids, Asphalt- Real Density and Asphalt-Compaction.

Taking the arithmetic average of the percentages of asphalt corresponding to the maximum points of the Asphalt-Stability curves obtained, it is controlled whether for that percentage of average asphalt content the absorption, swelling and voids values are satisfactory.

To accept a sand-asphalt mixture as recommended, it must meet certain requirements: Maximum absorption 8 %, Maximum swelling 5 %, Stability 72 hours (3 days) of partial immersion in water minimum 1,000 lb., Minimum air stability 1,200 lb. maximum void percentage 12 % and minimum compaction 88 %.

The adhesion must be satisfactory, otherwise, it will be recommended to use an additive that improves said adhesion. Another solution would be to look for another loan of sand that meets the requirements that classify it as a sample of good quality aggregate for asphalt mixtures.

Determination of the indirect tensile strength of the standard mix

Three mixture briquettes with optimal %RC-250 were prepared to carry out the indirect tensile test. In this test, a tangentially opposite load is applied to the briquette that produces indirect internal tensile stresses until failure occurs. As shown in Figure 6.

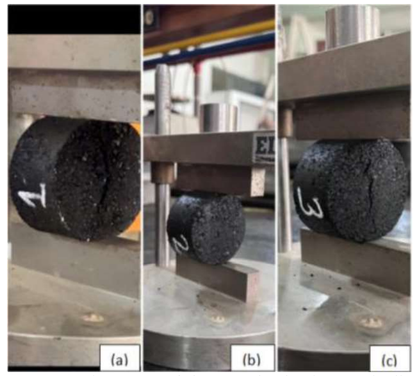

Fig. 6. Briquettes of the standard mixture, indirect tensile test.

2.2 Estimation of the percentage of fiber to reinforce the mixture

Design of the cold asphalt mixture modified with microfiber

For the design of cold asphalt mixture modified with microfiber, the same Hubbard-Field Method (sand-asphalt) was applied, but in this case part of the stone aggregate was replaced by different percentages of microfiber.

A volumetric correction was carried out to replace the stone material, which is heavier, with a material such as microfiber, which is lighter but takes up more volume in the mixture. This is based on its relative specific weight that varies by more than 20 %.

The mixture was prepared by weighing the amount of aggregates, microfiber and the optimal %RC-250 (Figure 7).

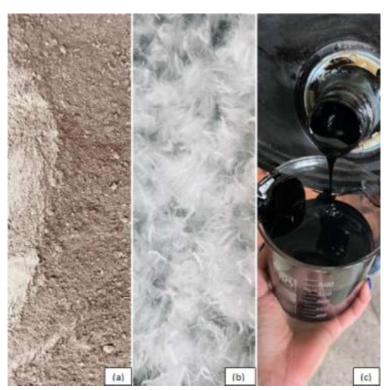

Fig. 7. Heavy materials for the manufacture of briquettes with cold asphalt mixture modified with microfiber.

Fifteen (15) briquettes of modified mixture were manufactured for each percentage of microfiber (0.05, 0.10 and 0.15 %) to replace the stone aggregate. These microfiber percentages were chosen based on previous experiences and recommendations used for concrete.
Table 2 shows the technical characteristics of the microfiber used.

Table 2. Characteristics, technical sheet of the microfiber.

Density (Kg/l)	Dimensions (mm)	Melting Point (°C)	Water absorption
0.91	6.00	160-170	None
Tensile strength (kg/cm^2)	Elasticity Module (kg/cm^2)	Elongation at Break (%)	
300-350	15000	20-30	

Mixing was completed when it was observed that the asphalt covered the entire aggregate and the microfiber was integrated uniformly. The same procedure was followed for the other mixtures. Result shown in Figure 8.

Fig. 8. Modified mixture with 0.10 % microfiber.

Curing of the mixtures

Then the mixture was placed in metal trays to be cured at room temperature for a period of 24 hours.

Compaction of briquettes

The compaction of these briquettes was carried out following the same process as the standard mixture.

Once all the briquettes were finished, they were left in the air at room temperature for 24 hours and then tested.
The number of briquettes made for each stipulated percentage of microfiber was 15 units, of which were used for the following tests: 3 briquettes for stability in air, 3 briquettes for stability after 1 hour in water at 60 °C, 3 briquettes for stability after 72 hours of partial immersion in water at room temperature, 3 briquettes for absorption and swelling test and 3 briquettes for indirect tensile test.
In addition, the following were determined: real density, theoretical density, compaction percentage, voids percentage and adhesion.
For the calculations, modified mixture stability testing and determination of the indirect tensile strength, the same procedure and methodology applied to the standard mixture was followed.

3 Results

3.1 Design of cold asphalt mixtures (Hubbard-Field Method (sand-asphalt), pattern mix

Characteristics of the aggregates

To achieve an adequate asphalt mixture, it is necessary to take quality control of the stone aggregates, as well as characterize the material to be used. Table 3 shows the wet granulometric test and the determination of the consistency limits of the aggregates, whose origin and location are described in the methodology.

Table 3. Characterization of the stone material.

Granulometric test and consistency limits						
%G	%S	%F	%a	%b	%c	%P
56.63	29.11	9.64	43.27	39.72	3.55	4.63
%Ll	IP	Cu	Cc	Classification		
17.39	NP	210.40	0.71	GP-GM		

%G, represents the percentage of gravel, %S, represents the percentage of sand, %F, is the percentage of fines, %a, represents the percentage of aggregate retained on the #10 sieve, %b is the percentage of aggregate passing through. #10 and retained in #200, %c, is the percentage of aggregate passing through #200, %P, is the approximate percentage of asphalt. %Ll, is the liquid limit, IP, represents the plastic index, Cu, is the uniformity index, Cc, is the curvature index, GP-GM, represents the SUCS classification.

The material resulting from the characterization is a poorly graded silty gravel; the sandy portion passing through sieve #4 was used for the asphalt mixture.

Approximate determination of the percentage of asphalt

Using equation 1 and data from Table 2, the approximate value of the liquid asphalt content in the standard mixture was determined.
This amount of liquid asphalt does not represent its optimal content; it is through the final application of the method that this optimal percentage is obtained.

Sample preparation

In order to determine the optimal % RC-250 in the standard mixture, eight (8) briquettes were made for each percentage of RC-250. Two (2) briquettes for each index property (Ambient temperature stability, Humidity stability at ambient temperature (72 h), Stability at 60 °C water and Stability at 60 °C oven) and three (3) for indirect traction.
Table 4 shows the tests used to find the optimal liquid asphalt content in the standard mixture.

Table 4. Liquid asphalt percentage scores.

Hubbard-Field method. Cold asphalt mixtures (sand-asphalt)				
Content %RC-250	5	7	8	9
Number of briquettes	11.00	11.00	11.00	11.00
Ambient temperature stability (lb)	958.10	1444.30	1758.90	1630.20
Stability Hum. at Temp. Environment (72 h) (lb)	729.30	786.50	2030.60	1615.90
Stability at 60 ºC water (lb)	200.20	214.50	343.20	314.60
Stability at 60 ºC oven (lb)	343.20	328.90	486.20	486.20
Swelling (%)	3.19	2.18	2.16	1.38
Absorption (%)	4.31	0.82	0.71	0.38
Compaction (%)	85.08	87.52	91.18	95.40
Voids (%)	15.23	12.23	8.86	4.69
Content %RC-250	10	12	13	
Number of briquettes	11.00	11.00	11.00	
Ambient temperature stability (lb)	2259.40	2187.90	972.40	
Stability Hum. at Temp. Environment (72 h) (lb)	2.145.00	2116.40	958.10	
Stability at 60 ºC water (lb)	429.00	514.80	314.60	
Stability at 60 ºC oven (lb)	586.30	529.10	243.10	
Swelling (%)	5.32	1.76	1.78	
Absorption (%)	2.16	3.89	5.58	
Compaction (%)	96.85	98.60	99.88	
Voids (%)	3.34	2.31	0.39	

From the result of Equation 1, points below this result were discarded, since at first glance it was determined that the mixture was poor in asphalt content, due to the low coverage of the aggregate.
Once the index properties of the mixture were reviewed, the optimal liquid asphalt content for the standard mixture was determined. Table 5 shows the results.

Table 5. Index properties of the mixture and determination of the optimal content of liquid asphalt.

Determination of the optimal RC-250 content for the master mix		
Liquid asphalt content		RC-250 (%)
Ambient temperature stability (lb)	2340.00	11.00
Stability Hum. at Temp. Environment (72 h) (lb)	2230.00	11.00
Stability at 60 ºC water (lb)	520.00	11.80
Stability at 60 ºC oven (lb)	580.00	10.40
Average RC-250 liquid asphalt content 11.05 %		
Checking the index properties of the mixture with RC-250=11.05 %		
Ambient temperature stability (lb). 1200 lb minimum	2340.00	Ok
Hum stability at Temp. Environment (72 h) (lb). 1000 lb minimum	2230.00	Ok
Swelling. 5 % maximum	3.60	Ok
Absorption. 8 % maximum	3.00	Ok
Compaction. 88 % mínimum	97.50	Ok
Voids. 12 % maximum	2.80	Ok
Optimal RC-250 content = 11.00 %		

The previous Table reflects that the optimal % RC-250 is quite far from the estimate made in equation 1 present in Table 4, this is possibly due to the fact that the stone material has a high absorption, which is why it is important to do absorption tests.

Determination of the indirect tensile strength of the standard mixture

The tensile strength of the standard mixture was 1.15 kg/cm2, this result was compared with the tensile strength of the modified mixture, to verify if this parameter improves by reinforcing the mixture with microfiber.

3.2 Design of the cold asphalt mixture modified with microfiber

An equal number of briquettes were made for each percentage of microfiber replaced, eleven (11) briquettes to determine the index properties of the mixture and three (3) to test them under indirect traction, with the optimal content of liquid asphalt and were compared with the mixture standard.
Table 6 shows the summary of results of the modified mixture compared to the standard one

Table 6. Index properties and indirect traction of the standard and modified mixture.

Index properties of the standard and modified mixtures				
Liquid asphalt content RC-250=11.00 %	Mix standard	Modified mixtures		
		Microfiber percentage		
		0.05	0.10	0.15
Ambient temperature stability (lb). 1200 lb minimum	2340.00	1630.20	1501.50	2002.00
Stability Hum. at Temp. Environment (72 h) (lb). 1000 lb minimum	2230.00	1372.80	1501.50	1849.47
Stability at 60 ºC water (lb)	520.00	486.20	343.20	357.50
Stability at 60 ºC oven (lb)	580.00	371.80	328.90	343.20
Swelling. 5 % maximum	3.60	1.98	1.48	2.38
Absorption. 8 % maximum	3.00	0.32	0.36	0.46
Compaction. 88 % mínimum	97.50	90.63	93.80	96.44
Voids. 12 % maximum	2.80	8.65	5.67	3.99
Indirect traction (σ_t) (Kg/cm^2)	1.15	0.98	1.09	1.38

4 Discussion

Stability of briquettes at room temperature

It is observed in Table 6 that the stability of the modified mixtures is affected by incorporating fiber to replace the stone material, this is because the aggregate, which provides resistance to compression, is partly replaced by the fiber that does not It is capable of withstanding this type of stress applied by the test equipment and, therefore, this property is affected. With the latest incorporation percentage there is an improvement in stability, so we must expand the added percentage and verify this trend.

Etability at room temperature of briquettes immersed in water for 72 hours.

Immersing the briquettes and subjecting them to an unfavorable condition such as humidity for a long time impairs the stability of the mixture. With the incorporation of microfiber, it can be noted that this property worsens, but with a recovery in the higher percentage of modification, this trend would have to be verified by increasing the percentage of fiber in the mixture.

Stability of briquettes immersed in water for 1 hour at 60 °C

In this case, stability is affected by testing the briquettes under very unfavorable conditions, such as humidity and temperature. There was a decrease in stability because a material that provides more resistance was replaced by another that does not have the same capacity.

Stability of briquettes in the oven for 1 hour at 60 °C

Another quite unfavorable condition is the high temperature to which a mixture may be subjected. It presented a decrease that occurs due to the incorporation of microfiber, a similar case and for the same reason why stability is affected in the previous cases.

Swelling of the mixture

In the case of swelling, the modifying material is a polymer that should not undergo volume change when in contact with water; however, the stone material, even though it is sand, can change its volume. A decrease in swelling is seen in the mixtures with 0.05 and 0.10 % microfiber compared to the standard mixture, this is because the microfiber does not change its volume and replaces part of the stone material that does. Now, when comparing the result of this property, of the mixture with 0.15 % with the mixtures of 0.05 and 0.10 % microfiber, an increase is noted, this trend must be verified by manufacturing and testing other blends with a higher percentage of microfiber.

Mixture absorption

Absorption is directly related to the porosity of the material; shows a considerable decrease, so it is assumed that the microfiber has little or no absorption capacity. This would have to be verified with additional and specific tests for this type of polymeric material.

Compaction of the mixture

By replacing stone material that weighs more than microfiber, but occupies less volume in the mixture, it affects its density and therefore the compaction percentage. For the mixtures with different percentages of microfiber (0.05, 0.10 and 0.15 %), an increase in the compaction percentage was noted, without reaching that of the standard mixture, this is because there is an increase in the weight of the mixture in a fixed volume. This growing trend must be verified with the increase in the amount of microfiber and how this affects this and other properties.

Voids in the mix

It is a behavior analogous to that presented in the compaction percentage, the higher the percentage of voids, the lower the compaction percentage. It can be noted that the incorporation of microfiber increases the voids, but the greater the amount of microfiber there is a decrease in them, since they are occupied by the modifying material. It should be noted that the results of the index properties of the mixtures are within the range established by the specifications.

Determination of the indirect tensile strength of the mixture modified with microfiber.

The tensile strength of the standard and modified mixture was compared. This parameter is the indicator necessary to achieve the general objective of this research. By increasing the amount of microfiber in the mixture, the ability to withstand tensile stresses improves, since it serves as a seam between the aggregate particles and makes the mixture more ductile and deformable.

Table 7 shows the percentage variation of the index properties and tensile strength of the modified mixtures with respect to the standard sample.

Table 7. Percentage variation of the index properties and indirect traction of the modified mixtures with respect to the standard mixture.

Liquid asphalt content RC-250=11.00 %	Modified mixtures		
	Microfiber percentage		
	0.05	0.05	0.05
Ambient temperature stability	-30.33	-35.83	-14.44
Stability Hum. at Temp. Environment (72 h)	-38.44	-32.67	-17.06
Stability at 60 ºC water	-6.50	-34.00	-31.25
Stability at 60 ºC oven	-35.90	-43.29	-40.83
Swelling	-45.00	-58.89	-33.89
Absorption	-89.33	-88.00	-84.67
Compaction	-7.05	-3.79	-1.09
Voids	208.93	102.50	42.50
Indirect traction (σ_t)	-15.17	-4.88	1.38

In Table 7 it can be noted that the incorporation of microfiber in the percentages of 0.05 and 0.10 % deteriorates the stability, compaction, voids and tensile strength. In the case of absorption and swelling, the improvement is seen with the incorporation of microfiber, since the reduction of these values is favorable for the mixture. For the percentage of 0.15 %, there is a recovery of all values, so it is necessary to consider evaluating other mixtures with higher percentages of microfiber.

5 Conclusions

Once the experimental process and analysis of results is completed, it can be concluded that cold asphalt mixtures can be modified with the synthetic polypropylene microfibers used in this research, which represents a contribution. Tables 6 and 7 show the results and variation of the index properties of the standard and modified mixture. Although these properties remain within the specifications required by the method used for the design, in most cases they present a deterioration when compared with the standard mixture.

The results show that for low percentages of substitution of aggregate for microfiber (0.05 and 0.10 %) there was a deterioration in the index and tensile strength properties of the modified mixture with respect to the standard mixture, especially in the stability and the percentage of voids, so it is not recommended to use this range of microfiber percentages. For 0.15 %, a recovery was observed in the index properties and it is necessary to expand the research by increasing these percentages in order to verify the behavior; In addition, establish a band of percentages where a substantial improvement is achieved.

An important aspect to highlight is the improvement that occurs in tensile strength with the latest addition of this microfiber (0.15 %).

6 Recommendations

Evaluate the behavior of the index properties of modified mixtures with microfiber percentages greater than 0.15 %.

Use other types of fibers, of different shapes and textures.

References

SikaFiber®-6 Micro. Polypropylene micro-fiber for concrete and mortar. https://col.sika.com/es/construccion/concreto/produccion-de-concreto-mortero-y-cemento/fibras-para-concreto-y-mortero/sikafiber-6-micro.html

Gavino, H. (2022). Mechanical resistance of cold asphalt mixtures with the addition of expanded polystyrene. Degree Work, Universidad Peruana Los Andes, ULPA Repository, Huancayo, Peru. https://repositorio.upla.edu.pe/bitstream/handle/20.500.12848/4133/T037_45447679_T.pdf?sequence=1&isAllowed=y

Gamboa, J. (2021). Comparative evaluation of asphalt mixtures with ABS and traditional polymers to improve mechanical properties in flexible pavements. Degree Project, César Vallejo University, Trujillo Peru. https://hdl.handle.net/20.500.12692/77019

Briceño, J. and González, G. (2016). Study of the index properties of hot asphalt mixtures incorporating recycled polystyrene material. Advances in science and engineering, Faculty of Engineering, University of Los Andes and Pontificia Universidad Católica del Ecuador, Ibarra headquarters, Chapter 11, page. 104. https://www.researchgate.net/publication/335277472_Capitulo_11

Adrianzen, O., Azula, J., Pacherres, C., Rodríguez, E. and Muñoz, S. (2022). Use of different types of fibers to improve the mechanical properties of the asphalt mixture. *Scielo, Infraestructura Vial*, 24 (43), 29-45, 2022. http://dx.doi.org/10.15517/iv.v24i43.47931

Cárdenas, V. (2021). Addition of plastic polyethylene fibers to improve the physical - mechanical behavior of cold asphalt mix, Tacna. Thesis to obtain the title of Civil Engineer, César Vallejo University. https://hdl.handle.net/20.500.12692/84964

Agathon, M., Si, N., Oh-Sun, K. and Jae, L. (2020). Performance of glass wool fibers in asphalt and concrete mixtures. *Materiales,* 13 (21), 4699. https://doi.org/10.3390/ma13214699.

Park, K.S., Shoukat, B. T., Yoo, Y. P. J. and Lee, L. S. H. (2020). Strengthening of hybrid glass fiber reinforced recycled hot-mix asphalt mixtures," *Construction and Building Materials, ELSEVIER*, vol. 258. https://doi.org/10.1016/j.conbuildmat.2020.118947

Al-Bdairi, A., Al-Taweel, H. and Noor, H. (2020). Improving the properties of asphalt mixture using fiber materials. *IOP: Ciencia e ingeniería de materiales,* 870, 1-9, 2020. DOI 10.1088/1757-899X/870/1/012092

Mohamed, M., Parry, T., Thom, N. and Grenfellb, J. (2020). Microstructure and mechanical properties of fibre reinforced asphalt mixtures. *Construction and Building Materials, ELSEVIER*, 24, 117932. https://doi.org/10.1016/j.conbuildmat.2019.117932

Shanbara, H., Shubar, A., Ruddock, F. y Atherton, G. (2020). Characterization of the rutting behavior of cold asphalt mixtures reinforced with natural and synthetic fibers through finite element analysis. *Advances in structural engineering and rehabilitation, Lecture Notes in Civil Engineering,* vol 38, 221–227, 2020. https://doi.org/10.1007/978-981-13-7615-3_20

Tien Do Duy-Liem, N., Vu-Tu, T., HT Tai, N. (2020). Effects of forta-fi fiber on the fatigue resistance of conventional asphalt mixtures. *Fifth International Conference on Green Technology and Sustainable Development (GTSD)*,37 (20307281),312-316. DOI: 10.1109/GTSD50082.2020.9303123

Javani, M., Kashi, E. and Mohamadi, S. (2019). Effect of polypropylene fibers and recycled glass on the mechanical properties of AC mixtures. *International Journal of Pavement Research and Technology*, vol 12, pag. 464–471. https://doi.org/10.1007/s42947-019-0056-6

Mardones, L., Calabi, F., Sanches, E., and Valdes, G. (2018). Evaluation of the mechanical properties of asphalt mixtures with the incorporation of synthetic aramid and polypropylene fibers. *Infraestructura Vial, vol.* 20 (36), 15-24. http://dx.doi.org/10.15517/iv.v20i36.37729

Hernández, A. and Rodríguez, L. (2018). Modification of asphalt mixtures ready for hot installation using glass fibers and SikaFiber® AD fibers. Work done to obtain the title of civil engineer, Pilot University of Colombia. http://cybertesis.uach.cl/tesis/uach/2008/bmfciw961a/doc/bmfciw961a.pdf

Preciado, J., Martínez, G., Dugarte, M., Bonicelli, A., Cantero, J., Vega, D. and Barros, Y. (2017). Improvement of the mechanical properties of hot asphalt mixtures using fibers and polymers in developing countries. *IOP: Ciencia e ingeniería de materiales,* 245 (022013). https://doi.org/10.1088/1757-899X/245/2/022013

Ballena, C. (2016). Use of polyethylene fibers from plastic bottles for their application in the design of cold ecological asphalt mixtures. Degree Work, *Señor de Sipan*

University. https://hdl.handle.net/20.500.12802/2256

Ferrotti, G., Pasquini, E. and Canestrari, F. (2014). Experimental characterization of high-performance fiber-reinforced cold mix asphalt mixtures. Construction and Building Materials, vol 57, 117-125. https://doi.org/10.1016/j.conbuildmat.2014.01.089

Kaloush, K., Biligiri, K., Zeiada, W., Rodezno, M. and Reed, J. (2010). Evaluation of fiber-reinforced asphalt mixtures through advanced material characterization tests. *Infraestructura Vial*, vol. 38 (4), 1-12. DOI:10.1520/JTE102442, https://www.researchgate.net/publication/237538977_Evaluation_of_Fiber-Reinforced_Asphalt_Mixtures_Using_Advanced_Material_Characterization_Tests

Guzmán, J. (2008). Pre-stressed asphalt layers with shape memory fibers SMA (Shape Memory Alloys) Nitinol. Master's Thesis. *University of Los Andes.* https://repositorio.uniandes.edu.co/bitstream/handle/1992/9785/u303259.pdf?sequence=1

COVENIN. (1993). Norma Venezolana, Asfaltos Diluidos. *COVENIN 1471:1993.*

Fondonorma. (1980). Norma Venezolana, Sector Construcción. *COVENIN 2000:1987.*

Hubbard, P. and Fiel, F.C. (1925). Asphalt Pavements. Mixtures. *The Asphalt Institute*. Stability and Related Test, 6-10.

ASTM (1998). Standard Test Method for Particle-Size Analysis of Soils,1998. *ASTM D422-63.*

ASTM (1983). Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils, ASTM D4318-17e1, vol. 04.08, 20, 1983.

ASTM (1985). Classification of Soils for Engineering Purposes: Annual Book of ASTM Standards, D 2487-83, 04.08, *American Society for Testing and Materials*, 395-408.

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