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SMA Blend Behavior with Cellulose Fiber, Adding Marble Powder as Filler

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Abstract— **In recent decades, great importance has been given to the development of asphalt mixtures for road construction. The research in this area has focused on the development of mixtures for folders that meet the requirements of longer life, less proficiency in the passage of vehicles, significant water repellency (high hydrophobicity), resistance to ultraviolet radiation, resistance to rain, increased adhesion with tires, better adhesion between asphalt and stone material, among others.**

Based on the above, experimental work was developed to prepare Stone Mastic Asphalt (SMA) mixtures, based on stone aggregates from the Lagunera Region, AC-20 asphalt cement in different percentages (5.0, 5.5, 6.0, 6.5, 7.0), cellulose fibers (0.5 %, 1 %, and 1.5 %) and 10 % of the total aggregates of marble residues (dust). The results in the Marshall test show excellent values in the specimens that were added with 1.0 % and 1.5 % cellulose fibers. It is important to note that a "base" mixture without cellulose fibers was prepared as a reference parameter, resulting in mixtures with cellulose fibers, had a better performance in the Marshall stability test.

Index Terms— **Asphalt mix, SMA mix, fiber blends, Marshall.**

I. Introduction

Asphalt technology has focused on the development of a type of layer that complies with: longer life, less shattering of vehicles, significant water repellency (high hydrophobicity), resistance to ultraviolet radiation, resistance to rain, increase when gripping with the tire, better adhesion between asphalt and stone material, easy repair of potholes, etc. All these conditions result in intense research that has led to the development of new asphaltic materials, as well as the use in other forms with applications to the stone substrate.

Asphalt is known by several names such as asphalt or bitumen, naphtha-bitumen, and asphalt cement. This product was known around 2500 BC. in Egypt, although at that time it was not used in the construction of roads [1]. There is currently a wide variety of applications; among which we can mention: asphalt layer, adhesives, sealants, waterproofing, among others. The volumes of the use of asphalt are very large, especially in the manufacture of asphalt layers, where it is considered the most important material. The wide use of asphalts in the construction of roads is due in large part to its low cost, its hydrophobicity properties, and its relative resistance to weathering. One of the ways to apply asphalt to a mixture is through high temperatures; however, it can also be done cold using emulsions commonly called *Asphalt Emulsions* [2].

In the mid-sixties, a construction technique for high strength asphalt binders was developed in Germany in response to the stringent demands of nail tires [3]. This technique is known as asphalt rock agglomerate, also known as Stone Mastic Asphalt, (SMA). One of the busiest roads in the world is in Dortmund, Germany, it was built in 1980 with SMA and cellulose fibers, more than 100,000 trucks pass through it without showing cracks or damages of any other type. Since then, the SMA has proven to be an excellent method of building asphalt layers, with great strength, highly durable, and safe. The SMA system is currently the standard construction method in Germany and is registered in the ZTV Asphalt StB '07 standard, [4].

The first research and application works were developed in 1968, by the Strabag flooring company in collaboration with J. Rettenmaier & Sôhne, a leading fiber company, who were looking for a mixture with the highest possible wear resistance to reduce the negative action of the tires with nails, used to circulate in the extreme conditions of the winter season. Once the ice was removed, these nails caused damage to the tread layer, requiring a repair of the layer at the end of winter; subsequently, it was found that these mixtures had greater durability than conventional ones, which led to them being regulated and included within the German specifications in the year 1984 [5].

The SMA mixtures were conceived with clear and well-defined objectives: to increase the durability, security, and stability of the land communication routes, as well as to generate savings in their construction. The resistance of the mixture is achieved through a granular structure of contact between the coarse particles, filled with binder rich in fiber and stabilized with fibers, the resulting pavements are highly resistant to permanent deformations, fatigue cracks, aging and they are less susceptible to the action of water, [3].

The SMA is a proven construction method in Germany, Europe, and Asia; In the United States since 1991 and in Mexico since 1995, to date there are several comparative studies and road sections with this type of mixtures, presenting a good behavior, confirming its duration, cost, and maintenance for which they were conceived.

In 1987, the United States invested 150 million dollars in research on asphaltic flexible pavements under the Strategic

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Highway Research Program (SHRP). Later, with the "Superpave" program, they investigate mixtures born in Germany known as SMA-type mixtures with cellulose fibers. Since there was a considerable difference in the design parameters, while the roads in Europe were planned with a life expectancy of 40 years with a permitted load of 11,000 kg per axle, in the United States the expectation of duration was 20 years with a load of 9,000 kg per axle. Finishing by using this technique (SMA) in some highway sections of the United States. Nowadays pavements built from SMA are also used by developed countries in Asia. Proof of this the Philippines, Taiwan, Hong Kong, South Korea, Japan, and China, use it on important roads [6].

Many advances have been made in the scientific and technological development of asphalt mixtures (through the use of various methods in developed countries), one can even say that in Latin America, Mexico is the most advanced country in this aspect; However, despite this progress, an approach oriented to hot mixtures of dense granulometry is maintained, leaving aside the possibility of using other related techniques such as asphalt mixtures of discontinuous granulometry, in this case, SMA.

A. *Importance of SMA mixtures*

These types of mixtures have a high initial cost, however, this is minimized over time, since they have excellent performance, require minimum levels of preservation, offer excellent driving properties, combine high stability with a longer duration, allow greater adhesion by therefore it improves driving safety, is resistant to wear and deterioration caused by tires and extreme conditions [7]. Currently, in Mexico, these types of mixtures are being introduced by government agencies, such as the Ministry of Communications and Transportation (SCT).

The SMA system with cellulose fiber contains a very high proportion of aggregates within a binder-rich chew. The structure of the support is a mineral skeleton of aggregates filled with high viscosity asphalt which results in a long-lasting asphalt agglomerate presenting roads that have remained for more than 40 years. The resistance of the skeleton of the aggregates is ensured by the load transfer "grain to grain". The fiber-reinforced asphalt binder has the mission of ensuring the long duration of the bonding of the particles of stone aggregates and of protecting them against forces caused by braking and acceleration. The compact structure of the aggregates has a rough finish that allows a good grip and prevents aquaplaning. They are also highly resistant to permanent deformations, fatigue cracks, aging, and are less susceptible to the action of water [3].

In Mexico, where the unexpected increase in cargo and transit volumes has subjected additional efforts to the Highway System, the reserve force of an SMA type pavement with cellulose fiber would prolong the life of existing roads, delaying costly modifications and improvements to the bases and bearing surfaces.

The construction of pavements with the SMA system increases productivity in construction and significantly reduces maintenance work.

B. *Characteristics of SMA type mixtures*

The fundamental principles of the design consider a mineral skeleton of high internal friction, high content of binder, and the presence of a stabilizing additive that distributes and prevents the runoff of the binder. The mineral skeleton provides a discontinuous granulometry with a high percentage of coarse aggregates (> 70 %) which allows that arid-arid contact, to make the waterproof mixture the holes are filled with a filler and binder mass that make this type of mixtures maintain a low hollow content [3].

Another of its characteristics is the high incorporation of the binder that varies between 6.0 and 7.5 % by mass of the total of the mixtures, this forms a thick layer around the aggregates, to prevent its runoff with high temperatures fibers are added that They keep it stable.

Among the stabilizing agents, there are polymers, powder-based additives, and fibers that can be synthetic, mineral, or of plant origin, which are of greater affinity with asphalt. Under suitable conditions the fiber wrap is easy and complete, it does not break easily during mixing has an irregular surface which facilitates three-dimensional interlacing. [8].

II. Materials and Methods

The resulting design was obtained based on the materials present in the Lagunera Region and with Viatop Premium cellulose fiber provided by the company SURFAX. The stone materials (crushed sand and gravel ¾") from the CRIBISSA material bank, located in Lerdo Durango, were analyzed to adjust them to the granulometric band (granulometric spindle) of the SCT regulations that apply for this type of mixtures. Likewise, marble waste (powder) from the "Mármoles Parra" was used, which is the product of cutting and polishing marble tiles. It is worth mentioning that 10 % was used in all mixtures made with fiber. The design mixtures were made using asphalt cement 20 (AC-20), varying the content of cellulose fibers in different percentages (0.5, 1.0, 1.5), trying to obtain the optimum asphalt content with which the lowest is obtained possible runoff.

Sixty standard specimens (briquettes), with a height of 64 mm (2 ½") and 102 mm (4") in diameter, were prepared to perform the tests required by the Marshall method, [9]. The results of the tests carried out on the briquettes were analyzed, to determine the optimum asphalt content with the lowest flow and the greatest stability of the specimen.

For the preparation of the mixtures, those indicated for SMA mixtures in the regulations of the Ministry of Communications and Transportation [10] were considered as reference parameters. These parameters can be seen in table 1.

Table 1. Design criteria for asphalt mixtures type S.M.A. designed under the Marshall methodology, Source: SCT Regulations.

Characteristics	**Requirement**
Number of blows each end with Marshall hammer	50
Air voids (VA) (% min)	4.0
Voids filled with asphalt (VFA) %	75-82
Voids in mineral aggregate (CMA) (% min)	17

Cellulose fibers content, as a percentage by mass (min)	0.3
Tensile strength retained (TSR) (% min)	80
Asphalt runoff at production temperature% Max	0.3
Asphalt cement content, as a percentage by mass of the sample	6.0

Table 2. Stone material quality requirements for asphalt mixtures of batch granulometry type S.M.A. Source: SCT regulations.

GRAVEL		
Los Angeles abrasion % max		25
Flat and elongated particles % max		25
Accelerated weathering % max	on sodium sulfate	15
	on magnesium sulfate	20
Crushed particles % max	one face	100
	two faces	90
Absorption		2
Friction detachment % max		10
SANDS AND FINES		
Sand equivalent % min		55
Plasticity index % max		No plasticity
Methylene blue mg/g max		12

Based on the N-CMT-4-04 / 08 SCT standard, the characteristics of the aggregates and their granulometry were obtained to compare the results obtained with the established reference parameters, see Table 2. The tests were carried out in the materials laboratory of the Faculty of Engineering, Sciences and Architecture of the Juarez University of Durango State.

Subsequently, the percentage of asphalt was calculated based on the method of the American Asphalt Institute [8], using (1).

$$P = (0.035*a) + (0.045*b) + kc + K \qquad (1)$$

where:

P = Percentage of asphalt cement with respect to the weight of the mixture

a = Percentage of aggregate retained in sieve No. 10

b = Percentage of aggregate that passes over sieve No. 10 and is retained in sieve No. 200

c = Percentage of aggregate that passes on sieve No. 200

k = Take the following values:

0.20 When the percentage of aggregate that passes on sieve No. 200 varies from 11 % to 15 %

0.18 When the percentage of aggregate that passes on sieve No. 200 varies from 6 % to 10 %

0.15 When the percentage of aggregate that passes on sieve No. 200 is less than 5 %

K = Varies from 0 to 2, depending on the degree of stone absorption.

High absorption: K = 2

A. *Experimental stage*

As part of the experimentation, 60 Marshall tablets with a weight of 1100 g each, were made, which were grouped as follows:

Group one: 5 sets of 3 tablets each, with a cellulose fiber content of 0.0 % by weight and varying asphalt content between 5.0 and 7.0 %, in 0.5 % intervals.

Group two: 5 sets of 3 tablets each, with a cellulose fiber content of 0.5% by weight and varying asphalt content between 5.0 and 7.0%, in 0.5 % intervals.

Group three: 5 sets of 3 tablets each, with a cellulose fiber content of 1.0 % by weight and varying asphalt content between 5.0 and 7.0 %, in 0.5 % intervals.

Group four: 5 sets of 3 tablets each, with a cellulose fiber content of 1.5 % by weight and varying asphalt content between 5.0 and 7.0 %, in 0.5 % intervals.

Each of the specimens was compacted with 50 strokes per face with the standard Marshall tamper. Subsequently, the necessary tests were carried out, to know the parameters indicated in the N-CMT-4-05-003 / 08 (SCT) standard, including the Indirect Traction test and the runoff test by the Shellenberg method [11], they compared the results to establish the best option of the proposed mixtures.

III. Results and Discussion

As a result of the granulometric analysis, it was found that none of the materials by itself meets the design percentages of the mixture, since they were not within the area defined in the graphs, so iterations were made by varying the percentages between each of the materials, until complying with the design curve, see figure 1.

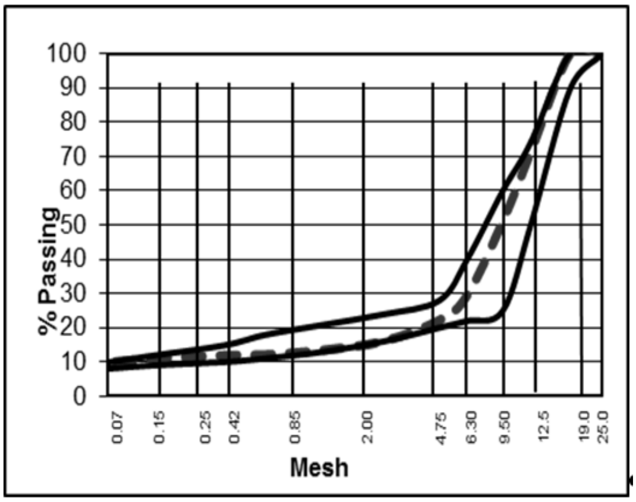

Fig 1. Granulometric composition, 80 % Gravel, 10 % dust and 10 % filler (marble dust).

TEST	MATERIAL				SCT STANDARD	
	GRAVEL ¾”	GRAVEL ½”	POLVILLO 3/16”	FILLER	MIN	MAX
Los Angeles abrasion	23 %	22 %	23 %	N/A		25%
Sulphate resistance	9 %	9%	N/A	N/A		15 %
Specific gravity and absorption	2.66, 0.6 %	2.66, 0.6 %	N/A	N/A		2%
Specific gravity and absorption	N/A	N/A	2.68, 0.6 %	2.7, 1.6 %		2.0%
sand equivalent	N/A	N/A	63 %	N/A	55 %	
Flat and elongated particles index	18 % 16 %	18 % 16 %	N/A	N/A		25 % 25 %
Fractured faces index	100 %	100 %	N/A	N/A		100 %

Table 3.- Characteristics of the aggregates.

The characteristics of the aggregates are shown below; it is observed in Table 3 that it complies with all the reference parameters indicated in the Mexican reference standard [12].

With respect to asphalt, after performing the necessary tests it was found that it complies with the quality parameters indicated in the standard [13] see Table 4.

Table 4.- Asphalt characteristics.

CHARACTERISTICS	ASPHALT CEMENT AC-20 NORMAL	STANDARD	
		Min	Max
Say bolt furol viscosity at 135º c, s.	136	120	
Penetration at 25ºc, 100 gr, 5 s. 0.1 mm	68	60	
Cleveland flash point, °C	245	232	
solubility %	99.5	99	
From the residue of the thin layer test			
Ductility 25 °C y 5 cm/m, cm	59	50	
Retained penetration at 25 °C %	58	54	
Loss on heating %	0.32		0.5

The asphalt percentage was obtained by substituting the values of equation 1, leaving:

$$P = (0.035*84) + (0.045*6) + 0.18 + 0.20$$

$$P = 5.39\% \approx 6\%$$

With the data obtained previously, we proceeded to calculate the volumetric weights of the test tablets and their voids, the results obtained are shown in Figure 2.

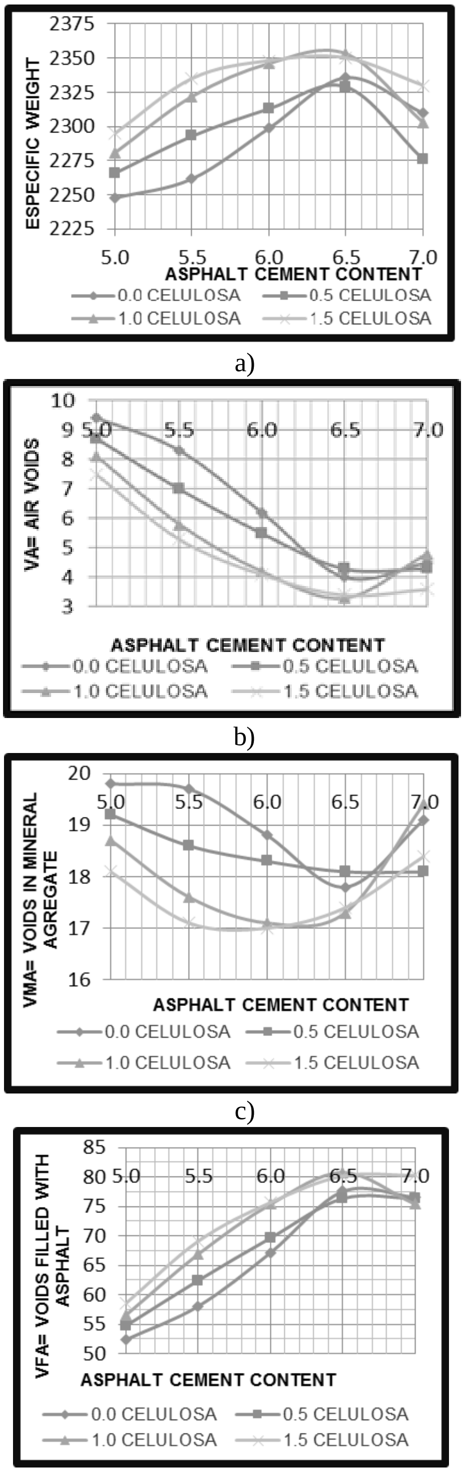

Fig. 2. Volumetric behavior of mixtures a) PE vs. % of C.A., b) VMC vs. % of C.A., c) VAM vs. % of C.A., d) VFA vs. % of C.A.

Table 5.- Summary of the results obtained.

GROUP	AC.	% FIBER	VAC	VSM	VA >4	VMA >17	VFA 75-82	ESTAB. >816	FLOW 2-3.5	OBSERVATIONS
G1C1	5.0	0.0	10.392	80.2	9.4	19.8	52.4	586	2.5	VFA <, EST <
G1C2	5.5	0.0	11.448	80.3	8.3	19.7	58.1	609	3.3	VFA <, EST <
G1C3	6.0	0.0	12.632	81.2	6.2	18.8	67.2	668	3.9	VFA <, EST <, FL >
G1C4	6.5	0.0	13.844	82.2	4.0	17.8	77.6	760	4.3	EST <, FL >
G1C5	7.0	0.0	14.672	80.9	4.5	19.1	76.6	732	4.0	EST <, FL >
G2C1	5.0	0.5	10.477	80.8	8.7	19.2	54.7	636	2.4	VFA <, EST <
G2C2	5.5	0.5	11.607	81.4	7.0	18.6	62.4	658	2.5	VFA <, EST <
G2C3	6.0	0.5	12.713	81.7	5.5	18.3	69.6	739	2.9	VFA <, EST <
G2C4	6.5	0.5	13.801	81.9	4.3	18.1	76.3	825	3.3	
G2C5	7.0	0.5	13.801	81.9	4.3	18.1	76.3	752	2.9	EST <
G3C1	5.0	1.0	10.544	81.3	8.1	18.7	56.5	668	2.8	VFA <, EST <
G3C2	5.5	1.0	11.751	82.4	5.8	17.6	66.9	803	3.0	VFA <, EST <
G3C3	6.0	1.0	12.893	82.9	4.2	17.1	75.4	898	3.7	FL >
G3C4	6.5	1.0	13.941	82.7	3.3	17.3	80.8	976	4.1	VA <, FL >
G3C5	7.0	1.0	14.625	80.6	4.8	19.4	75.4	855	3.2	
G4C1	5.0	1.5	10.612	81.9	7.5	18.1	58.5	689	3.1	VFA <, EST <
G4C2	5.5	1.5	11.817	82.9	5.3	17.1	69.1	833	3.1	VFA <, EST <
G4C3	6.0	1.5	12.903	83.0	4.1	17.0	75.7	971	3.3	
G4C4	6.5	1.5	13.925	82.6	3.4	17.4	80.2	987	3.4	VA<
G4C5	7.0	1.5	14.802	81.6	3.6	18.4	80.3	876	3.4	VA<

In Fig. 2, it is observed that some mixtures comply with what is established in Mexican regulations, however, there are some parameters that are outside the specification, therefore only the mixtures with the best characteristics were chosen to undergo the tests of Indirect traction and runoff test.

Fig. 3 shows that the mixtures with the best performance in Marshall stability are those with 1 and 1.5 % cellulose fibers. Below is a summary of the results obtained to define the mixtures with the best performance.

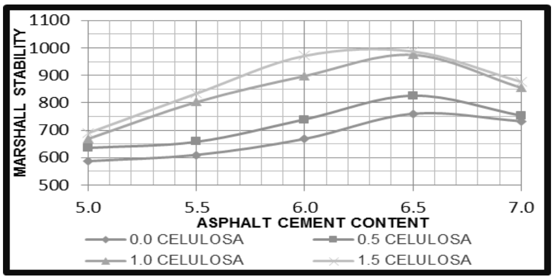

Fig. 3.- Behavior of the mixtures, Marshall stability.

As can be seen in Table 5, several mixtures complied with various parameters and failed in some others, so the mixtures that do not comply with the parameters indicated in the N-CMT-4-05-003 / 16 SCT norm were eliminated.

Only the mixtures remaining: G2C4, G3C5, and G4C3, which were subjected to the indirect tensile test.

Table 6.- Results of the Indirect Traction test.

GROUP	A.C.	% FIBER	TSR DRY	TSR SAT	% TSR	OBSERVATIONS
G2C4	6.5	0.5	947	696	73.5	TSR <
G3C5	7.0	1.0	1052	869	82.6	OK
G4C3	6.0	1.5	1011	821	80.6	OK

Table 7.- Results of the runoff test.

GROUP	% A.C.	% FIBER	TOTAL	RUN OFF	%	Observations
G3C5	7.0	1.0	1026.50 GR	2.64 GR	0.257	ok
G4C3	6.0	1.5	1041.26 GR	2.18 GR	0.209	ok

The results of the indirect tensile test, are shown in Table 6. Since the mixtures G3C5 and G4C3 comply with the aforementioned regulations (see Table 6), the value of the percentage of runoff to said mixtures was finally calculated, obtaining the results shown in Table 7.

It is observed in Table 7, that the two mixtures that were subjected to the runoff test comply with the established parameters.

IV. Conclusion

As it was observed in the results obtained initially, several mixtures met some parameters and failed in others. Through the indirect tensile and runoff tests, it was determined which mixtures meet all the parameters indicated in the N-CMT-4-05-003 / 16 SCT standard, the selected mixtures are mentioned below:

G3C5 Asphalt mix with 1.0 % cellulose fiber and 7.0 % asphalt cement content.

G4C3 Asphalt mix with 1.5 % cellulose fiber and asphalt cement content of 6.0 %.

The choice of the design mix will depend on what is sought in each specific project and according to the cost-benefit ratio. That is, although it is true, one of the mixtures carries less fiber but requires more asphalt; while the other with the highest percentage of fiber demands a lower percentage of asphalt.

Also, there is a considerable variation in Marshall stability, since the first mixture has a value of 855 kg and the second 971 kg, very important data in the choice of design mix.

It is important to mention that the results obtained will be limited by the presence of similar materials, otherwise significant variations in the characteristics of the mixture may occur.

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