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Behavior of a Porous Asphalt Mixture Modified with Gilsonite

Hugo Alexander Rondon-Quintana[1], Saieth Chaves-Pabón[2] and Diego A. Escobar[3*]

[1]Universidad Distrital Francisco José de Caldas, Facultad Del Medio Ambiente y RecursosNaturales, Bogotá DC., Colombia; harondonq@udistrital.edu.co
[2]Universidad Militar Nueva Granada, Facultad de Estudios a Distancia, Programade Ingeniería Civil, Bogotá, DC, Colombia; saieth.chaves@unimilitar.edu.co
[3]Universidad Nacional de Colombia – Sede Manizales. Facultad de Ingeniería y Arquitectura. Departamento de Ingeniería Civil. Cra 27 # 64-60, Manizales, 170004, Colombia; daescobarga@unal.edu.co

Abstract

Objectives: The study presents the experimental results of testing an MD-1 porous asphalt mixture modified by wet and dry process with a natural asphalt type Gilsonite (G) from Cesar (Colombia). **Methods/Analysis:** For the preparation of the mixtures, an Asphalt Cement (AC) type AC 60-70 (PG 64-22) was used. For the evaluation of the resistance to abrasion and monotonic load of the control mixtures (without Gilsonite) and modified, the Cantabro and Marshall tests were used, respectively. **Findings:** We report a remarkable increase in the stiffness under monotonic load and in the resistance to abrasion when a ratio of Gilsonite and AC of G/AC=10% is used. **Application/Improvement:** Gilsonite can be used to improve resistant to abrasion and cohesion properties (increasing stiff and monotonic mechanical resistance) of porous asphalt mixtures which are used in pavements to improve wet-weather visibility and friction, tire spray, hydroplaning, storm water management and skid resistance.

Keywords: Cantabro Abrasion Resistance, Gilsonite, Modified Asphalt Mixture, Porous Asphalt Mixture, Resistance Under Monotonic Load

1. Introduction

In the world, the asphalt mixtures that most extend and compact in situ are those of asphalt concrete. These mixtures are of the dense type, that is, they have well-graded particle sizes and low voids with air in volume. Its low porosity generates mixtures that are more resistant to mechanical loads and damage by moisture and aging compared to porous asphalt mixtures (poorly graded particle size and air voids greater than 10%). Mainly for this reason, the dense type asphalt mixtures are the preferred ones to be used as bituminous layers of pavements.

In spite of the above, mixtures of the dense type have as main limitations or disadvantages:

- Low texture and superficial porosity, which decreases the pneumatic-pavement friction and increases the degree of accident on the roads,
- During rain they generate a phenomenon called hydroplaning that also helps to increase the degree of accidents in the roads, and
- Rolling noise is greater.

These disadvantages that are evident in the dense type mixtures are solved with the use of porous mixtures. One way to generate a porous asphalt mixture with strength and stiffness similar to that of a dense one is to use modified asphalt technology. By modifying the traditional asphalt and stiffening it by adding an additive, one could think of obtaining a porous mixture that has good resistance characteristics, and adequate porosity, which allows good pneumatic-pavement contact (superficial fiction) and decrease during rain of the phenomenon of hydroplaning. To obtain a mixture of this type, in the present study the base asphalt cement and a porous asphalt mixture were modified using Gilsonite from Cesar (Colombia) as an

**Author for correspondence*

additive. This additive was chosen because in Colombia there is a large number of a natural asphalt deposit, mainly in the departments of Boyacá, Caquetá, Caldas, Cundinamarca, Tolima, Santander and Cesar. This Gilsonite has been used successfully to modify Hot Mix Asphalt (HMA) and evaluates its properties under monotonic and dynamic load[1-3]. The results obtained from the previous studies have shown that the asphalt mixes of the HMA type modified with the Gilsonite by wet way (adding it to asphalt cement) and dry way (adding it to the granular aggregate of the mixture) generate more stiff mixtures of HMA, leading to think that they would perform well in hot climates. In these studies, the values of stability, Marshall Stiffness and resilient modulus of the modified mixtures have been higher, for any percentage of asphalt and Gilsonite, in comparison with the control mixture. This allowed us to conclude that Gilsonite as an asphalt modifier can be a material that improves the characteristics of stiffness and resistance to permanent deformations of HMA that are used in hot climates. A similar conclusion was reported by[4] using ethylene vinyl acetate and Gilsonite and by[5] when they modified by wet way asphalt cement from Alaska with Gilsonite in percentages between 3% and 12% with regarding the total weight of the asphalt. Esfeh[6], mention, that adding Gilsonite to asphalt helps to increase the viscosity and decreases the penetration, stiffening the binder. A similar conclusion is reported by[7] modifying an asphalt cement AC 50-70 (0.1 mm) with Gilsonite in percentages of 5%, 10% and 15% with respect to the total mass of the asphalt. According to[8-10], this type of natural asphalt has high softening points (above 90 °C) and is known worldwide as asphalt hardener materials due to its high asphaltene content. Several authors have reported increases in resistance to permanent deformation, fatigue and moisture damage when asphaltites and Gilsonite are added to asphalt mixtures[11-20].

For the study, the draining type was used as a porous asphalt mixture. In Colombia, draining mixtures are designated as MD-1 according to the "Instituto Nacional de Vías" (National Institute of Roads, INVIAS, 2013, article 453-13). These mixtures have granular aggregates with poorly graded particle size, predominantly thick solid particle size generally mixed with a modified asphalt cement, they extend and compact at high temperature and are characterized by a high content of voids (between 20% and 25%).

The study presents an experimental phase designed to evaluate the resistance to abrasion and under monotonic loading of a porous asphalt mixture type MD-1 modified with the aforementioned Gilsonite. The Asphalt Cement (AC) used for the manufacture of the mixtures is the AC 60-70 (it refers to a AC whose measurement in the penetration test ASTM D-5 is in a range between 60 to 70 mm/10). This binder has a performance grade PG 64-22. The Gilsonite was added to the asphalt (wet way) and to the granular aggregate (dry way) of the asphalt mixture at high temperature. The Cantabro (NLT 352/86) and Marshall (AASHTO T 245-97) tests were used to evaluate the mechanical resistance to abrasion and monotonic loading of the asphalt control mixtures (without additive or Gilsonite) and modified.

2. Materials and Methods

2.1 Characterization of Materials

The specified tests for asphalt mixtures were carried out on the granular aggregate and the AC 60-70, following the

Table 1. Characterization of the aggregates

Test	Method	Recommended Value	Result
Specific gravity/fine aggregate absorption	AASHTO T 84-00	-	2.64/1.9%
Specific gravity/gross aggregate absorption	AASHTO T 85-91	-	2.52/1.7%
Sand equivalent test	AASHTO T 176-02	50% mín.	72%
Fractured particles (1 side)	ASTM D 5821-01	85% mín.	88%
Fractured particles (2 faces)	ASTM D 5821-01	70% mín.	83%
Soundness of aggregateusing magnesium sulphate	AASHTO T 104-99	18.0% máx.	12.2%
Plasticity Index	ASTM D4318-00	Not plastic	Not plastic
10% of fines (dry resistance)	DNER-ME 096-98	100 kNMín.	135 kN
Micro-Deval	AASHTO T327-05	20% máx.	19.7%
Abrasion in Los Angeles machine	AASHTO T 96-02	25% máx.	24.4%

Table 2. General characteristics of asphalt cement AC 60-70

Test	Method	Unit	Recommended Value	Result
Tests on the original asphalt				
Penetration (25°C, 100 g, 5 s)	ASTM D-5	0.1 mm	60-70	67
Penetration Index	NLT 181/88	-	-1/+1	-0.1
Viscosity (60°C)	ASTM D-4402	Poises	1500 mín.	1850
Softening point	ASTM D36-95	°C	N.A.	51
Ductility (25°C, 5cm/min)	ASTM D-113	cm	100 mín.	>105
Water content	ASTM D-95	%	0.2 máx.	<0.2
Flash and fire points	ASTM D-92	°C	232 mín.	275
Tests on the residue after RTFOT (Rolling Thin Film Oven Test)				
Mass loss	ASTM D-2872	%	1.0 máx.	0.3
Penetration (25°C, 100 g, 5 s)	ASTM D-5	%	52 mín.	70

specifications of the INVIAS[21,22]. The results of these tests are presented in Tables 1-2. It is observed that the values meet the minimum quality requirements mandatory by the specifications INVIAS[21] to manufacture type MD-1 mixes for transit NT3 (high volumes). The granular size distribution of the granular aggregate is presented

Figure 1. Gilsonite before grinding.

Table 3. Particle size distribution of MD-1

Sieve		Percent passing (%)
Normal	Alternate	MD-1
19.0 mm	3/4"	100
12.5 mm	1/2"	85
9.5 mm	3/8"	62.5
4.75 mm	No. 4	23.5
2.00 mm	No. 10	14.5
425 µm	No. 40	8.5
75 µm	No. 200	5

in Table 3. In addition, the asphalt was characterized by using a Dynamic Shear Rheometer (DSR), obtaining a performance grade of PG 58-22.

The Gilsonite used comes from the San Alberto Mine (César, Colombia). A detailed description of the Gilsonite can be found[23]. This material has a specific gravity of 1.10 g/cm3 and particles of brilliant black coloration that pass the No. 40 sieve in a particle size test (Figure 1). On the control and modified AC, penetration tests (ASTM D-5) were carried out at different temperatures and softening point (ASTM D36-95) following the procedures recommended[22].

2.2 Asphalt Control Mix Design

The porous asphalt mixture was designed based on the Cantabro test (dry and wet condition). The porous mixtures were designed from cylindrical Marshall-type specimens, made as described in the test standards NLT 352/86. The air voids of the compacted mixture were measured as indicated in the AASHTO T 269-97 test standards. Additionally, the results of running the Marshall test (AASSHTO T245) were taken into account for the design, but performing said test under a temperature of 25 ° C, since at 60 ° C, which is the specified temperature, the mixtures tend to crumble because of the high content of voids with air. The Marshall test was carried out in order to evaluate the resistance of the mixtures under monotonic load. The samples were compacted at 50 blows per face and the masses of them were 1000 and 1200 g for the Cantabro and Marshall tests, respectively. To comply with the specifications INVIAS[21] and manufacture asphalt mixtures type MD-1, the original particle size distribution of the aggregates was modified, taking as reference the average values in percentages of the granulometric range (Table 3) that the specification for the preparation of the samples.

For the Cantabro and Marshall tests, five samples were manufactured and tested for each percentage of asphalt of 3.5%, 4.0%, 4.5% and 5.0%, in order to carry out the design and determine the optimum asphalt content. The calculations obtained from the tests are recorded in Table 4. The optimum percentage of asphalt is 4.5%, since with this content of AC 60-70 the mixture presents a percentage of voids between 20% and 25% and loss in the Cantabro test by dry and wet condition less than 25% and 40% respectively. Additionally, this percentage is the minimum required by INVIAS[21] for the production of draining or porous asphalt mixtures.

2.3 Experimental Phase

With the optimum percentage of AC of 4.5%, new samples were manufactured for the Cantabro and Marshall tests, adding the Gilsonite (G) by wet and dry process, in percentages of G/AC = 0, 5, 10, 15, 20, 25 and 30% (with respect to the mass). G/AC=0 means the control asphalt mixture (without addition of G). For each percentage of additives, five samples were manufactured for each test. The mixing temperature of the AC with G was 160 °C and the mixing time was 40 minutes when the addition was

Table 4. Summary of tests for asphalt mix MD-1

AC [%]	Marshall Test				Loss in Cantabro Test	
	Bulk density [g/cm^3]	Stability (*S*) [kN]	Air voids [%]	*S/F* ratio [kN/mm]	Dry [%]	Wet [%]
3.5	1.85	10.05	21.7	2.64	37.8	61.7
4.0	1.87	9.88	21.1	2.41	25.2	43.9
4.5	1.92	9.53	20.3	2.27	24.3	38.8
5.0	1.99	8.54	17.5	1.90	21.9	33.0

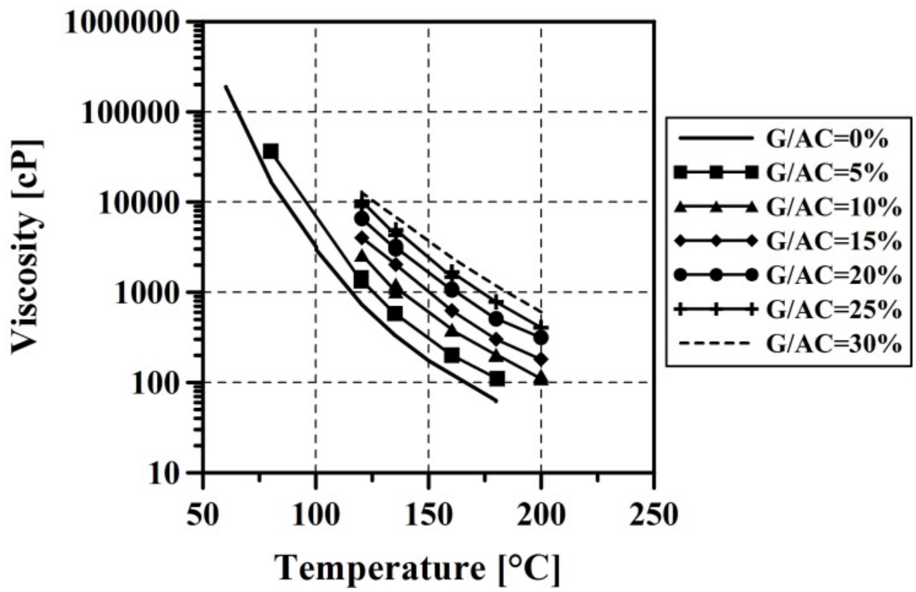

Figure 2. Evolution of viscosity with temperature.

performed by wet condition. In order to determine the mixing and compaction temperatures, through the criterion of equi-viscosity, the evolution of the viscosity was measured in the laboratory with the temperature of each of the modified asphalts (G/AC = 5, 10, 15, 20, 25 and 30%). Using the equi-viscosity criterion and the results of Figure 2, the compaction and mixing temperatures would be high. Therefore, they were chosen as temperature of mixture and compaction of the samples 160 °C and 155 °C respectively, and were determined empirically (by trial and error) in such a way that a good wrap of the aggregate was obtained with the AC modified without producing binder leaks or crumbling of the samples. Additionally, it was taken into account[24-26]:

- That it is widely recognized in the world, that the equi-viscosity method for modified asphalt is not reliable, mainly because the behavior of these materials is strongly dependent on the shear speed (non-Newtonian fluid), and the temperatures reported by this method are usually very high and unrealistic, degrading the original properties of the binder by oxidizing it and aging it,
- That these temperatures (160 °C and 155 °C) have been used by various researchers in the production of asphalt mixtures modified with plastomeric and elastomeric polymers. The Asphalt Institute, for example, recommends reducing between 14 °C and 25 °C the compaction temperatures of modified asphalt mixtures, determined from the criterion of equi-viscosity, and
- It was sought to use temperatures in which the stone aggregate did not alter its resistance to fracturing during compaction in the laboratory, that the asphalt was not oxidized excessively, that the manufacture of mixtures did not generate high polluting emissions to the atmosphere and that mixing it will not be difficult especially when the content of Gilsonite is high.

3. Results and Discussion

Figures 3-4 show the results of the Cantabro test and the evolution of the mass loss in dry and wet condition respectively, for the MD-1 mixtures modified with Gilsonite. It is observed that the best behavior is reached by wet-modified mixtures. The greatest increase in abrasion resistance due to dry abrasion and after immersion in the Cantabro test is observed when the mixture is modified by wet way with a G/AC ratio = 15% and 10%, respectively.

In the Marshall test (Figures 5-6) a remarkable increase in the resistance and stiffness under monotonic load of the draining mixture is also observed when it is modified by wet process. The greatest increase is reported when

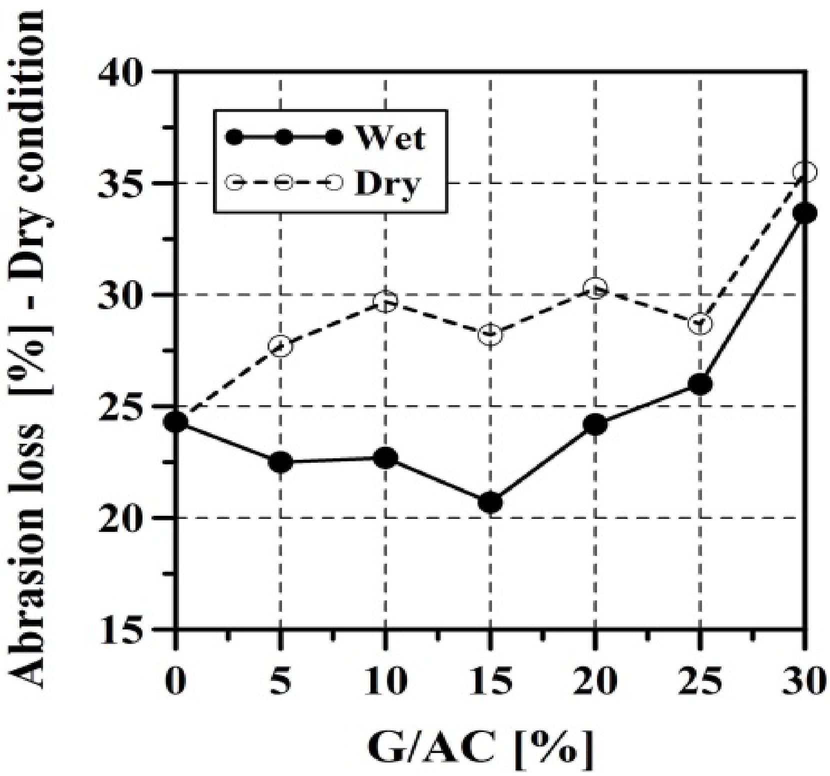

Figure 3. Cantabro test results - dry loss.

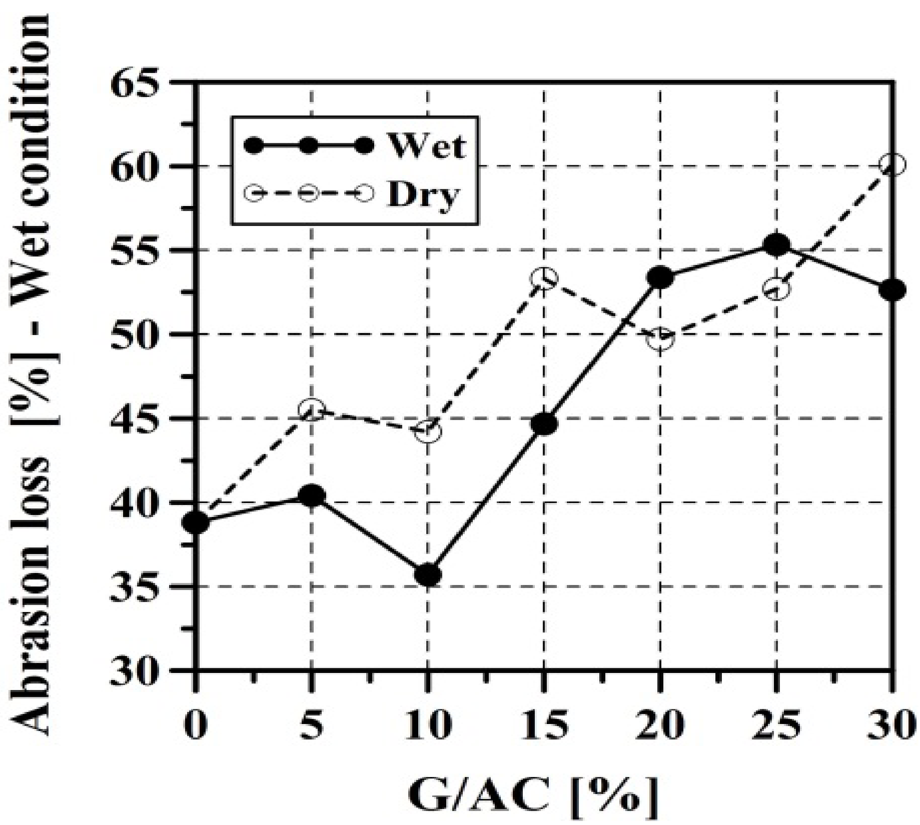

Figure 4. Cantabro test results - wet loss.

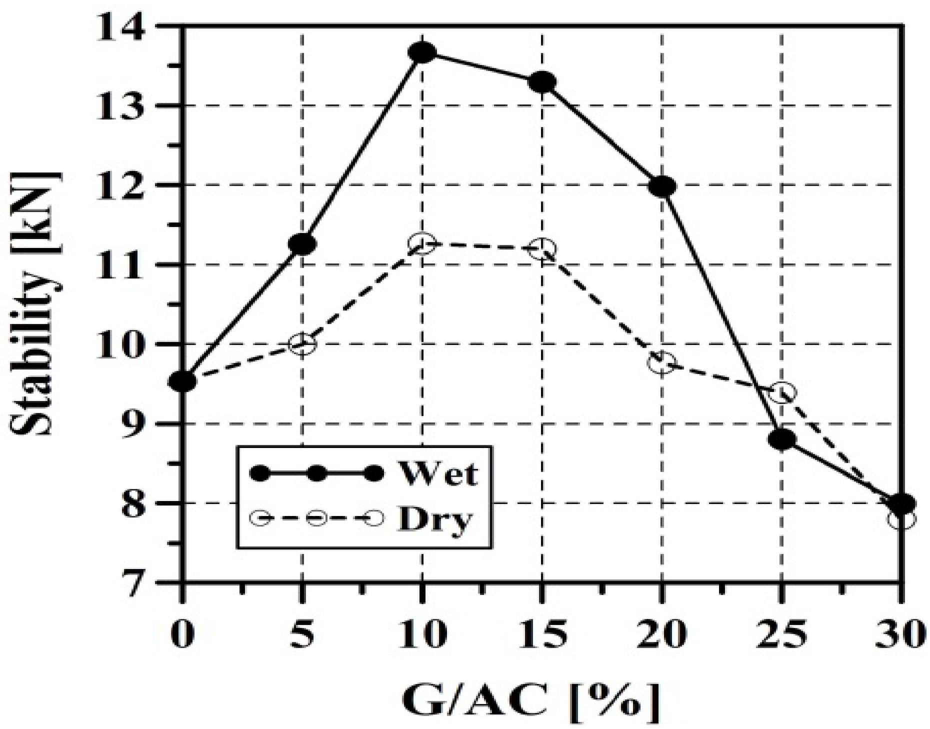

Figure 5. Marshall test results – stability.

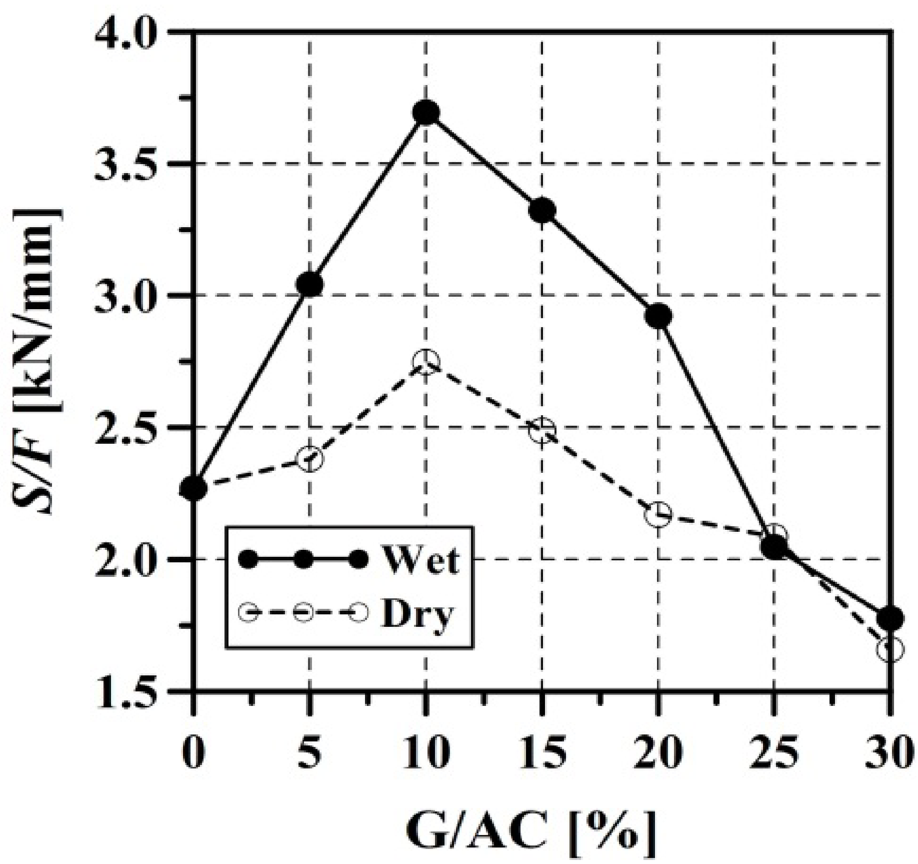

Figure 6. Marshall test results - stability / flow.

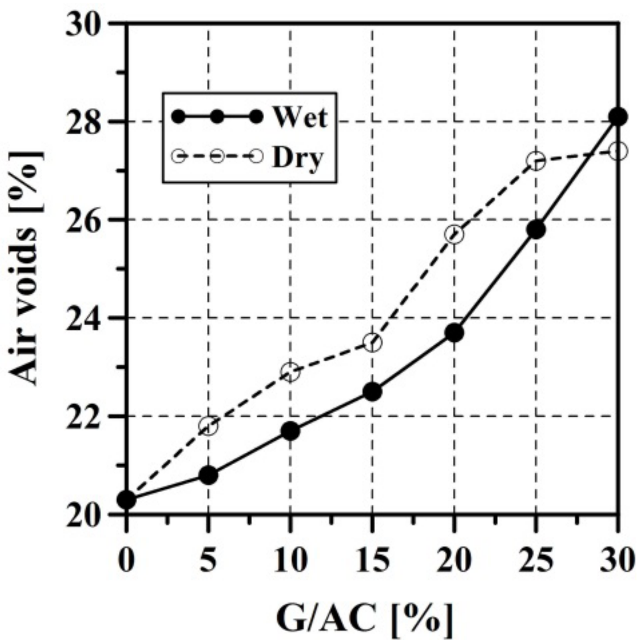

Figure 7. Evolution of voids with air in the mixture.

G/AC is used in a proportion of 10%. In this percentage of additive and asphalt, the asphalt mixture reached an increase of 4.13 kN of Marshall stability and 1.42 kN/mm

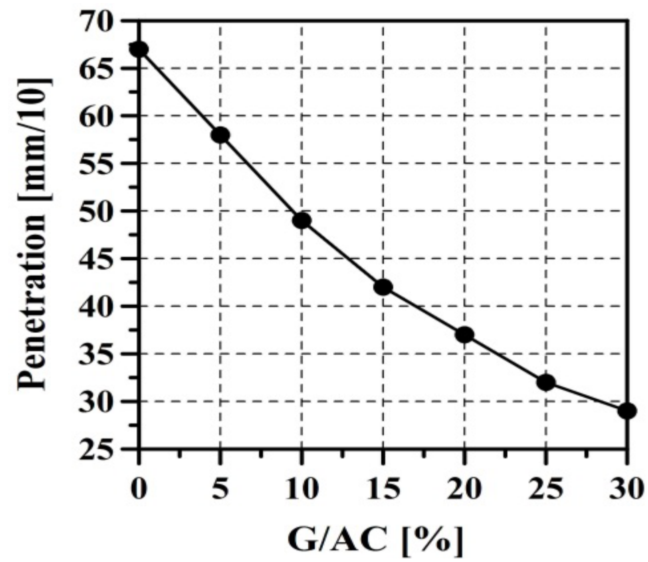

Figure 8. Evolution of the penetration with the content of G.

in the E/F ratio. The E/F ratio, called by some researchers as Marshall Stiffness or Marshall Quotient, can be understood as a mechanical resistance evaluated in the failure state of the mixtures. In the case of the dry-modified

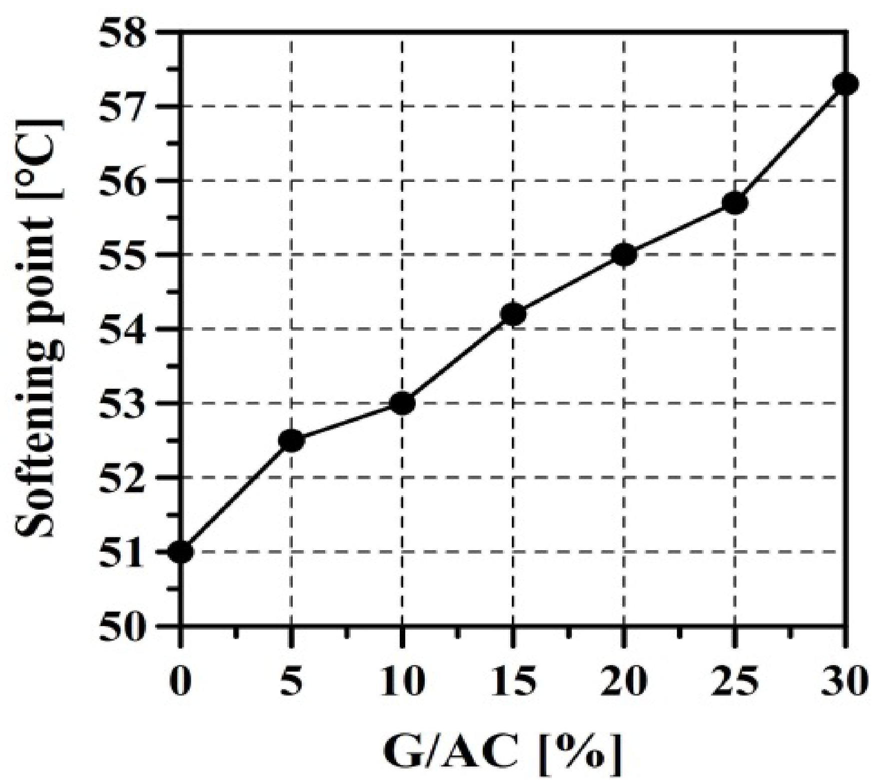

Figure 9. Evolution of the softening point with the content of G.

mixture, a slight increase of 1.73 kN of Marshall stability and 0.48 kN/mm in the E/F ratio was also observed when G/AC = 10%. It is interesting to note that this increase in strength and stiffness is obtained in the mixtures even though their voids with air increase (Figure 7).

The increase in strength and stiffness reached by the porous asphalt mixture analyzed when Gilsonite is added is mainly due to the increase in the stiffness of the asphalt. Figures 8-9 show the results of the penetration evolution and the softening point. It is observed in Figures 2, 8 and 9 that the Gilsonite, when added to the AC, generates a binder with a more stiff consistency, evidenced by the increase in viscosity, the decrease in penetration and the increase in the softening point.

4. Conclusions

The present study measured the resistance to abrasion and the resistance under monotonic load reached by a porous asphalt mixture when modified by wet and dry way with a natural asphalt type Gilsonite. In the case of porous mixtures, the use of Gilsonite as a modifier of the asphalt binder improves the resistance to abrasion and the resistance to monotonic loads. This improvement is obtained mainly when the addition of the Gilsonite is carried out by wet way in a proportion of 10% of the mass with respect to that of the asphalt. The Gilsonite, when added to the asphalt, generates a more stiff and viscous consistency binder, evidenced by the increase in viscosity, the decrease in penetration and the increase in the softening point. The results of the study allow us to foresee that Gilsonite as an asphalt modifier can be a material that allows to improve the characteristics of stiffness and resistance to permanent deformations of porous asphalt mixtures. The values of the resistance parameters under monotonic load obtained by the porous asphalt mixtures modified with Gilsonite are comparable with those reported for mixtures of asphalt concrete.

Future phases of the study should measure properties such as short-term and long-term aging of modified asphalts, and stiffness under repeated loading, resistance to fatigue and rutting of asphalt mixtures modified with Gilsonite. Furthermore, in order to understand the changes that occur in the physical and mechanical properties of the modified asphalt mixtures, it is necessary to evaluate the changes in the chemical properties.

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