THE IDEAL ASPHALT FOR FLEXIBLE PAVEMENTS

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ABSTRACT

Asphalt concrete is a paving material that consists of asphalt binder and mineral aggregate. The asphalt binder acts as a binding agent to glue aggregate particles into a cohesive mass and also functions to waterproof the mixture, for this reason is a very interesting construction material which to work. The asphalt binder has limitations as many materials, these conditions are been studying by researchers with the object to obtain the ideal asphalt.

An ideal asphalt must have a special viscosity performance in three temperature intervals as follow: 1) Lower viscosity respect to the original asphalt at the temperatures between 100°C and 160°C to provides benefits at which asphalt mixes are produced and placed. 2) Higher viscosity than the original asphalt at the temperatures between 52°C and 82°C to reduced permanent deformation problems. 3) Lower viscosity respect to the original asphalt at temperatures lower than 25°C to reduce fatigue-cracking problems.

In this study a new additive has been developed to obtain ideal asphalt. Adding this additive into the asphalt is possible to obtain the ideal asphalt performance. Also, using this additive, the problem of asphalt oxidation was reduced as well as the moisture sensitivity in the asphalt mixtures.

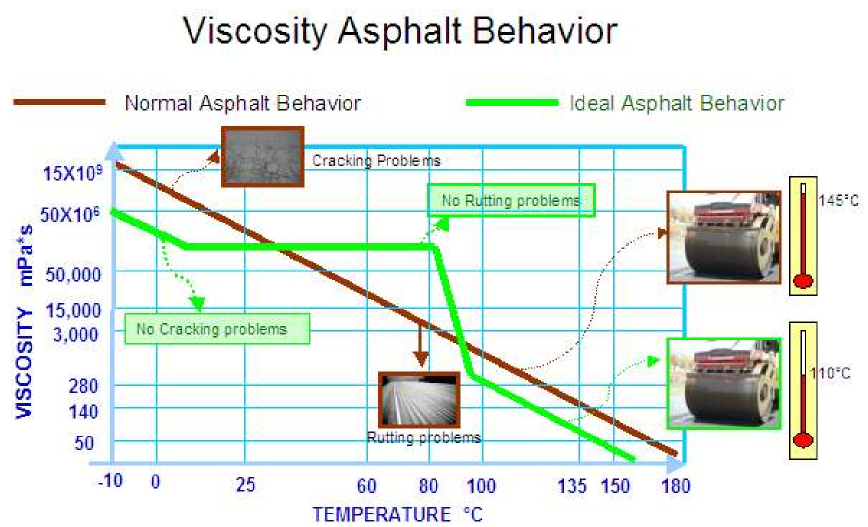
1. INTRODUCTION

Asphalt concrete (sometimes referred to as "hot mix asphalt" or simply "HMA") is a paving material that consists of asphalt and mineral aggregate. The asphalt acts as a binding agent to glue aggregate particles into a cohesive mass. Because it is impervious to water, the asphalt also functions to waterproof the mixture. When bound by the asphalt, mineral aggregate acts as a stone framework to impart strength and toughness to the system. Because HMA contains both asphalt and mineral aggregate, the behaviour of the mixture is affected by the properties of the individual components and how they react with each other in the system, but in this study only were analysed the properties that must to have the ideal asphalt to obtain a Hot Mix Asphalt of high quality.

Asphalt is a very interesting and challenging construction material with which to work, but as all materials have strengths and weaknesses. The five principal weaknesses of the asphalt are the following:

- Asphalt has high viscosity at temperatures between 100 y 160°C.
- Asphalt at temperatures between 58 and 82°C has the consistence of viscous fluid.
- Asphalt at low temperatures can be brittle.
- Asphalt reacts with oxygen.
- Asphalt does not have affinity with the aggregate.

In this study a chemical additive base fatty polyamines and derivates was developed to solve these five weaknesses of the asphalt obtaining the ideal asphalt performance. The figure one shows the lineal performance viscosity of a normal asphalt as function of temperature (from the mixing temperature until pavement service temperatures), and also the special viscosity performance of the ideal asphalt in the three temperature intervals: 1) Lower viscosity respect to the original asphalt at the temperatures between 100°C and 160°C to provides benefits at which asphalt mixes are produced and placed. 2) Higher viscosity than the original asphalt at the temperatures between 52°C and 82°C to reduced permanent deformation problems. 3) Lower viscosity respect to the original asphalt at temperatures lower than 25°C to reduce fatigue-cracking problems.



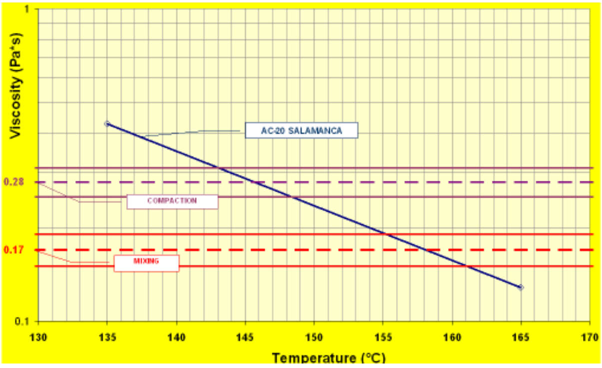
"Figure 1 - Lineal performance viscosity of the normal asphalt and special performance viscosity of the ideal asphalt".

Many additives are used to improve the asphalt performance but only resolve two or three of the five principal weaknesses of the asphalt, probably the most commonly used asphalt modifier in the world is Styrene-Butadiene-Styrene (SBS) because is an elastic polymer, but using this polymer the asphalt viscosity at the temperatures between 100 and 160°C is high, so is difficult the mixing and compaction process [1]. The additive developed in this study, reduce the five weaknesses of the asphalt became a smooth and elastic asphalt in all the range of temperatures improved the PG grade at high and low temperatures as well as decrease the viscosity of the asphalt at the temperatures between 100 and 160°C. This additive is a polyamide obtained from the reaction of a fatty acid with a mix of different amines and is completely soluble in the asphalt and storage stable. The incorporation of this additive in the asphalt is easy and fast, only is necessary to heat the asphalt at the temperatures between 150 and 155°C and add the additive and mix during 30 minutes.

1.1. Asphalt shows high viscosity at temperatures between 100 y 160°C.

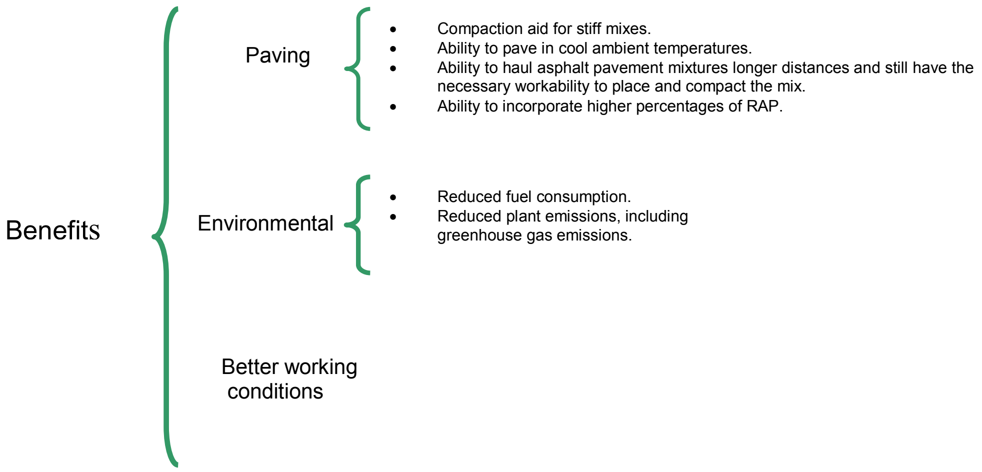
For years, asphalt mix design procedures have used equiviscous temperature ranges for selecting laboratory mixing and compaction temperatures. The Asphalt Institute's Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, began recommending laboratory mixing and compaction temperature ranges based on asphalt viscosity as early as 1962. At that time, viscosity ranges were specified based on Saybol-Furol viscosity. In 1974, the MS-2 manual recommended viscosity ranges of 170 ± 20 centistokes for mixing temperatures and 280 ± 30 centistokes for compaction temperatures when performing a Marshall mix design. Many years later, the same ranges have been recommended for Superpave mixture design, except that the units have been converted to metric: 0.17 ± 0.2

Pascal-seconds for mixing temperatures and 0.28 ± 0.3 Pascal-seconds for compaction temperatures and the resulting graph of the viscosity-temperature relationship is usually assumed to be linear when viscosity is plotted on a double log scale (Pa-s) and temperature is plotted on a log scale (°C), one example of this graph is showed using asphalt AC-20 from Salamanca Mexico refinery in next figure 2.



"Figure 2 - Temperature-viscosity graph of the asphalt AC-20 from Salamanca to determination of mixing and compaction temperatures ".

The temperatures determined using the viscosity range of 0.17 ± 0.2 Pascal-seconds for mixing temperatures are not intended for field production only for laboratory, depending on the gradation (fines content) of the mixture, the type of plant and the mixing time. The appropriate field mixing temperature for proper coating may be 5 to 20°C lower than the laboratory temperature determined by this method. The field compaction temperature usually is the same range as the laboratory compaction temperature (0.28 ± 0.3 Pascal-seconds), controls all of the plant operations for the project but is affected by several factors: air temperature, base temperature, wind speed, haul distance, roller type and lift thickness. For modified asphalt binders, the field mixing temperature for proper coating is usually higher than that for unmodified binders. Mixes with modified binders can also be expected to support the roller passes at a higher temperature [2].
With the object to reduce the high viscosity of the asphalt at the temperatures between 100 and 160°C a group of technologies were developed, the name of these technologies is Warm-Mix Asphalt (WMA). Warm-Mix Asphalt represents a group of technologies which allow a reduction in the temperatures at witch asphalt mixes are produced and placed. These technologies tend to reduce the viscosity of the asphalt and provide complete aggregate coating at lower temperatures. The reduction in viscosity at production and placement temperatures provides a number of potential benefits [3]. The range of potential benefits are showed in the next figure 3.

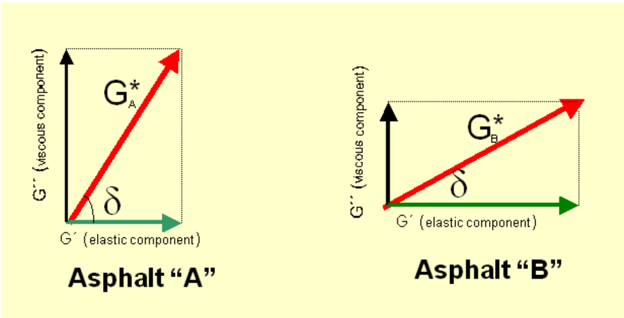


"Figure 3 - The range of potential benefits of the Warm Mix Asphalt".

The Warm Mix Asphalt technologies only change the asphalt viscosity behaviour respect to normal asphalt in the temperature range between 100 and 160°C, but the ideal asphalt propose in this study, changes the asphalt viscosity like Warm Mix Technologies and too changes the asphalt viscosity at low temperatures respect to normal asphalt (figure 1).

1.2. Asphalt at the temperatures between 58 and 82°C shows the consistence of viscous fluid.

At the temperatures between 58 to 82°C or under sustained loads (slow moving or parked trucks), asphalt acts like a viscous liquid and stars flowing does not return to its original position. This is why in hot weather, some less stable hot mix asphalt pavements flow under repeated wheel loads and wheel path ruts form. However, rutting in asphalt pavements during hot weather is also influenced by aggregate properties and is probably more correct to say that the asphalt mixture is behaving like a plastic [4].
Under normal pavement temperatures and traffic loadings, asphalt binders act with the characteristics of both viscous liquids and elastic solids. By measuring G* (complex shear modulus) and δ (phase angle) using the dynamic shear rheometer (DSR) that provides a more complete picture of the behaviour of asphalt at pavement service temperatures. The vector arrows in the figure 4, G^*_A and G^*_B represent the complex shear modulus of Asphalts "A" and "B". When these asphalts are loaded, part of their deformation is elastic (G') and part is viscous (G''); therefore, asphalt is a viscoelastic material. Even though both asphalts in the figure 4 are viscoelastic and have the same G*, Asphalt "B" is more elastic than Asphalt "A", because of its smaller δ[4]. Because Asphalt "B" has a larger elastic component, it will recover much more deformation from an applied load. This example clearly shows that G* alone cannot describe asphalt behaviour, the value of δ is also needed [4]. The propose of this study is to obtain an ideal asphalt performance and also obtain a smooth but elastic asphalt with a smaller value of δ at the temperatures between 58 and 82°C for resolve this weakness of the asphalt.



"Figure 4 - Viscoelastic behaviour of the asphalt".

1.3. Asphalt at low temperature can be brittle.

In cold climates (winter days) or under rapidly applied loads (fast moving trucks), asphalt cement behaves like an elastic solid. Elastic solids are like rubber bands; when loaded they deform, and when unloaded, they return to their original shape. If stressed beyond material capacity or strength, elastic solids may break. Even though asphalt cement is an elastic solid at low temperatures, it may become too brittle and crack when excessively loaded [5]. For this reason, low temperature cracking sometimes occurs in asphalt pavement during cold weather. In these cases loads are applied by internal stresses that accumulate in the asphalt pavement when it tries to shrink while being restrained by the lower pavement layers (when temperatures fall during and after a sudden cold front). The propose of this study is to obtain an ideal asphalt performance decreasing the asphalt viscosity at low temperatures obtaining a smooth asphalt for resolve this weakness of the asphalt.

1.4. Asphalt reacts with oxygen from the environment.

Because asphalt cements are composed of organic molecules, they react with oxygen from the environment. This reaction is called oxidation and it changes the structure and composition of asphalt molecules. Oxidation causes the asphalt cement to become more brittle, generating the term oxidative hardening or age hardening. Oxidative hardening happens at a relatively slow rate in a pavement, although it occurs faster in warmer climates and during warmer seasons. Because of this hardening, old asphalt pavements are more susceptible to cracking. Improperly compacted asphalt pavements may exhibit premature oxidative hardening. In this case, inadequate compaction leaves a higher percentage of interconnected air voids, which allows more air to penetrate into the asphalt mixture, leading to more oxidative hardening. In practice, a considerable amount of oxidative hardening occurs before the asphalt mix is placed. At the hot mixing facility, asphalt cement is added to the hot aggregate and the mixture is maintained at elevated temperatures for a period of time. Because the asphalt cement exists in thin films covering the aggregate, the oxidation reaction occurs at a much faster rate. Other forms of hardening include volatilisation and physical hardening. Volatilisation occurs during hot mixing and construction, when volatile components tend to evaporate from the asphalt. Physical hardening occurs when asphalt cements have been exposed to low temperatures for long periods. When the temperature stabilizes at a constant low value, the asphalt cement continues to shrink and harden. Physical hardening is more pronounced at temperatures less than 5°C and must be considered when testing asphalt cements at very low temperatures[4]. The propose of this study is to obtain an ideal asphalt performance and also obtain a resistant asphalt to oxidation, specially after the RTFO test the asphalt must be change a few its original properties for resolve this weakness of the asphalt.

1.5. Asphalt does not have affinity with the aggregate.

Stripping is the process by which the bond between the asphalt and aggregate is broken by the action of water. This is based on a chemical phenomenon where water molecules alter the interactions between the asphalt and aggregate surface. Aggregates have a higher affinity for water than for asphalt and so they are more readily wetted by water than asphalt. Adhesion, as it pertains to asphalt and aggregate interaction, is generally defined as the formation of a chemical bond between asphalt and the aggregate. Water will penetrate through asphalt by osmosis, which has been well established. The rate of osmosis of water through the asphalt film would depend on the thickness of the asphalt film and the pressure difference across the asphalt film, Also, softer grades are more permeable to water because of lower viscosity [6]. The propose of this study is to obtain an ideal asphalt performance that has a high affinity with the aggregate increasing the bond between both for resolve this weakness of the asphalt.

2. EXPERIMENTAL PROGRAM

Mexico is one of the main countries in the world that produce petroleum and has six refineries, although only asphalt is produced in: “Salamanca”, “Salina Cruz”, “Cadereyta”, “Madero” and “Tula”. The Salamanca refinery is the biggest (@16,528 barrels by day), for this reason in this study the mains results were obtained using the asphalt AC-20 produced in this refinery. One hundred samples of this asphalt from Salamanca were obtained and analysed obtaining an average sample, this means that after the analysis of the one hundred samples, one was selected having the average performance. Sometimes asphalt samples from the refinery of Salina Cruz are using in this study and asphalt samples from other countries too, specially one asphalt from the refinery of

"Barrancabermeja" in Colombia named asphalt Barranca 60-70, which is asphalt AC-20 type.
The experimental program was designed to show the five weaknesses of the asphalt type AC-20 from Mexico and of others countries and using the special additive propose in this study the five weaknesses of the asphalt were reduced.

The experimental program begins showing that the asphalt has high viscosity at temperatures between 100 y 160°C and using the additive propose in this study the viscosity of all the asphalt samples were reduced and the temperature of mixing and compacting were reduced too according the Superpave specifications showed in the figure 2.
To show that the asphalt at temperatures between 58 y 82°C shows the consistence of viscous fluid, the standard specification for Performance-Graded Asphalt Binder AASHTO M320 was used, where permanent deformation is governed by limiting " $G^* / \text{sen}\ \delta$ " at the test temperature to values greater than 1.00 KPa for original asphalt and 2.20 KPa after RTFO aging following the method AASHTO T 315.

To show that Asphalt at low temperatures can be brittle the Bending Beam Rheometer (BBR) was used according with the standard specification AASHTO M320. The test method uses beam theory to calculate the stiffness of an asphalt beam sample under a creep load. By applying a constant load to the asphalt beam and measuring the center deflection of the beam throughout the four-minute test procedure, the creep stiffness (s) and creep rate (m) can be calculated.

To show that the asphalt reacts with oxygen the standard specification AASHTO M320 was followed using the rolling thin film oven (RTFO) and the pressure aging vessel (PAV) procedures and the viscosity of all the asphalt samples were evaluated at the temperatures between 7 an 31°C after these tests with the object to show how the asphalt viscosity increase with the oxidation of the asphalt.

To show that the between asphalt and aggregate exist a high interfacial tension the test ASTM D-3625 was used. In the procedure of this test, a sample of loose asphalt mixture is placed in boiling water for 10 minutes and then removed, the extent of retained asphalt coating on the aggregate is then evaluated relative to a non-conditioned sample.

The additive propose in this study was added to asphalt at the dosages of 3.0, 5.0, and 11.0% respect to the asphalt. The asphalt temperature was 150°C and the dispersion time was 30 minutes.

3. RESULTS AND COMMENTS

The results of this study show the five weaknesses of the asphalt AC-20 from Salamanca and from other countries, but using the additive propose in this study these five weaknesses were reduced specially using 11.0% of this additive respect to the asphalt. Using this additive and this dosage the ideal asphalt for flexible pavements was obtained.

3.1. Results to show that the asphalt has high viscosity at temperatures between 100 y 160°C.

The table 1, shows the viscosity of the asphalt AC-20 from de refinery of Salamanca at temperatures between 120 and 150°C using the average asphalt sample described in the experimental program, this sample was used in all the study.

Viscosity of the Mexican Asphalt AC-20 from Salamanca

Temperature °C	Viscosity Pa.s	Temperature °C	Viscosity Pa.s
120.2	0.9958	140.6	0.3532
120.8	0.9584	141.2	0.3443
121.4	0.9264	141.8	0.3342
122	0.8964	142.4	0.326
122.6	0.8678	143	0.319
123.2	0.8399	143.6	0.3111
123.7	0.8117	144.1	0.3025
124.3	0.7874	144.7	0.2949
124.9	0.7638	145.3	0.2878
125.5	0.7396	145.9	0.2819
126.1	0.716	146.5	0.2746
126.7	0.6948	147.1	0.2676
127.2	0.6739	147.6	0.263
127.8	0.6528	148.2	0.257
128.4	0.6317	148.8	0.2502
128.9	0.613	149.4	0.2443
129.6	0.5963	150	0.2393
130.1	0.5792	155.6	0.191
130.7	0.5631	158.1	0.172
131.3	0.5452	161.3	0.150
131.9	0.5298		
132.5	0.5148		
133	0.5005		
133.6	0.4861		
134.2	0.4725		
134.8	0.4604		
135.4	0.4487		
136	0.4356		
136.5	0.4228		
137.1	0.4135		
137.8	0.4026		
138.3	0.3919		
138.9	0.3816		
139.5	0.3703		
140.1	0.3611		
140.6	0.3532		

Compaction temperature range (143.6–148.8 °C)

Mixing temperature range (155.6–161.3 °C)

"Table 1 - Data of the viscosity vs. temperature of the asphalt AC-20 from the refinery of Salamanca (average sample) in the temperature range from 120 to 150°C".

The table 2, shows the viscosity of the asphalt AC-20 from de refinery of Salamanca plus 11.0% of the additive propose in this study at the temperatures between 120 and 150°C, the range of mixing and compaction temperature is reduced respect to normal asphalt (without additive).

Viscosity of the Mexican asphalt AC-20 from Salamanca plus 11.0% of additive

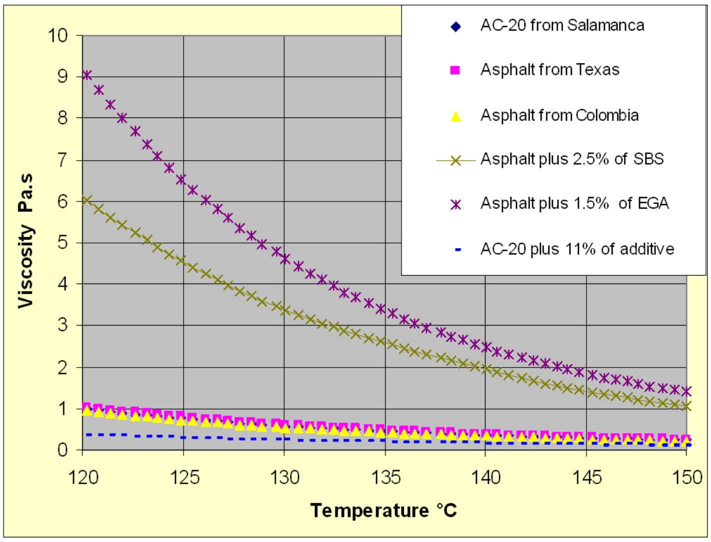
Temperature °C	Viscosity Pa.s	Temperature °C	Viscosity Pa.s
120.2	0.3664	141.3	0.1521
120.8	0.3596	141.8	0.155
121.4	0.3513	142.4	0.1481
122	0.3372	143	0.139
122.6	0.3219	143.5	0.1359
123.1	0.3178	144.1	0.1403
123.7	0.3155	144.7	0.1402
124.3	0.3038	145.3	0.1326
124.9	0.291	145.9	0.1239
125.4	0.2825	146.5	0.1256
126.1	0.282	147.1	0.1294
126.6	0.2773	147.6	0.1245
127.2	0.2657	148.2	0.1164
127.8	0.253	148.8	0.1123
128.4	0.2505	149.4	0.1171
129	0.251	150	0.1191
129.6	0.2421		
130.1	0.2317		
130.7	0.2237		
131.3	0.2256		
131.9	0.2238		
132.5	0.2139		
133.1	0.2023		
133.6	0.2006		
134.2	0.2028		
134.8	0.1975		
135.4	0.1882		
136	0.1802		
136.5	0.1827		
137.2	0.1838		
137.7	0.1753		
138.3	0.1659		
138.9	0.1694		
139.5	0.1675		
140	0.1591		
140.6	0.1505		

Compaction temperature range (123.7–129 °C)

Mixing temperature range (134.8–140.6 °C)

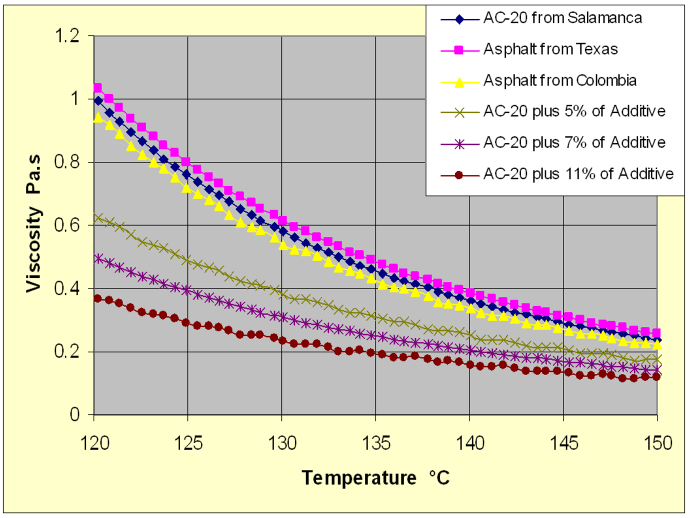
"Table 2 - Data of the viscosity vs. temperature of the asphalt AC-20 from the refinery of Salamanca plus 11.0% of additive in the temperature range from 120 to 150°C".

The figure 5 shows the high viscosity of the asphalts modified with the polymers SBS and EGA at the temperatures between 120 and 150°C respect to the viscosity of the asphalts type AC-20 from Mexico and of other countries, so, using these polymers the mixing, the workability and the compaction of the asphalt mixtures can be difficult for increment viscosity. Using 11.0% of the additive propose in this study, the asphalt viscosity is reduced respect to the asphalt viscosity type AC-20 and so much respect to modified asphalt viscosity obtaining benefits such as fuel savings, reduced emissions, decrease worker exposure and improved compaction for reduced temperatures.



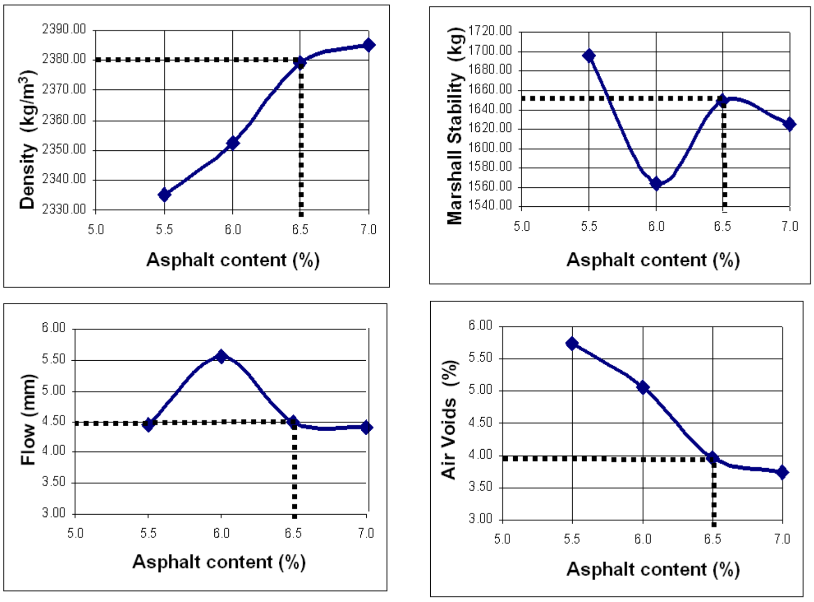
"Figure 5 - Viscosity of modified asphalts with polymers and viscosity of asphalts type AC-20 from Mexico and other countries in the temperature range from 120 to 150°C".

The next figure 6 shows the asphalt viscosity reduction using different percentages of the additive propose in this study respect to the viscosity of the asphalts type AC-20 from Mexico and other countries. The best reduction asphalt viscosity was obtained using 11.0% of additive and with this dosage the ideal asphalt performance was obtained.



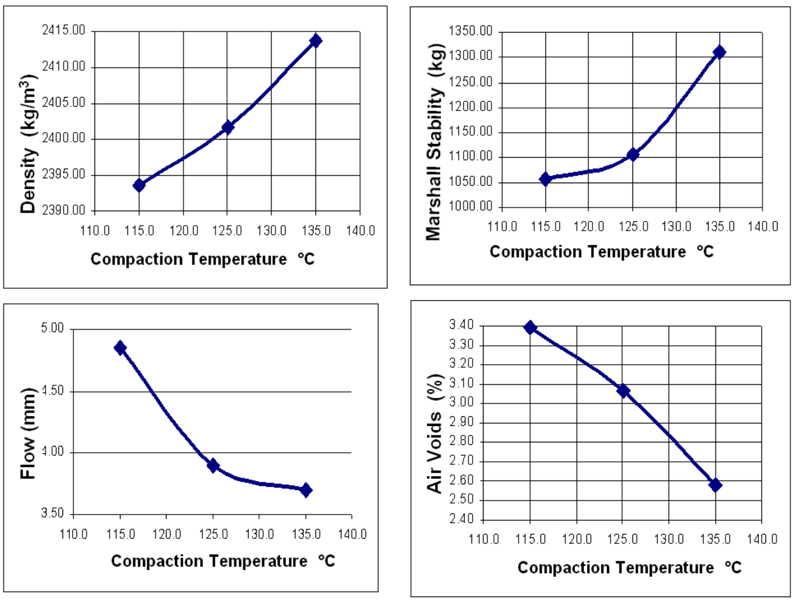
"Figure 6 - Viscosity of asphalts type AC-20 from some countries and viscosity of AC-20 from Salamanca using different dosage of the additive in the temperature range from 120 to 150°C".

A Marshall design was done using the asphalt AC-20 from Salamanca, the mixing temperature range was between 155.6 to 161.3°C and the compaction temperature was between 143.6 to 148.8°C according with the results show in the table 1 and using Superpave specifications for laboratory mixing and compaction temperatures. The figure 7 shows the results Marshall design where the optimum asphalt content was 6.5% with 4.0% of air voids and the value of the density mix design was 2,380 Kg/m^3.



"Figure 7 - Marshall design results of the asphalt mix using asphalt AC-20 from the refinery of Salamanca, the optimum asphalt content was 6.5%, the mixing temperature range was between 155.6 to 161.3 and the compaction temperature range was between 143.6 to 148.8".

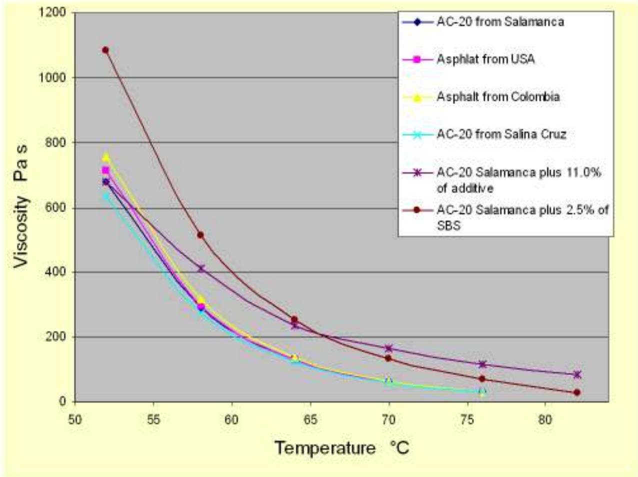
Other Marshall design was done with the same asphalt AC-20 from Salamanca plus the addition of 11.0% of the additive propose in this study, the mixing temperature range was between 134.8 to 140.6 and the specimens were compacted at the temperatures of 135, 125 and 115°C. The figure 8 shows the results of this Marshall design where all the tests were made with an asphalt content of 6.5% (same that the Marshall design using normal asphalt AC-20 from Salamanca). The compaction temperature was reduced with the object to find the minimum temperature to get the density of the original Marshall design (2,380 Kg/m^3); using 115°C of compaction temperature the density value of the mix was 2394 Kg/m^3 and air voids value of 3.4% was obtained by the effect of the additive propose in this study.



"Figure 8 - Reduction of the compaction temperature in the Marshall design using 6.5%of the asphalt AC-20 from the refinery of Salamanca plus 11.0% of the additive propose in this study".

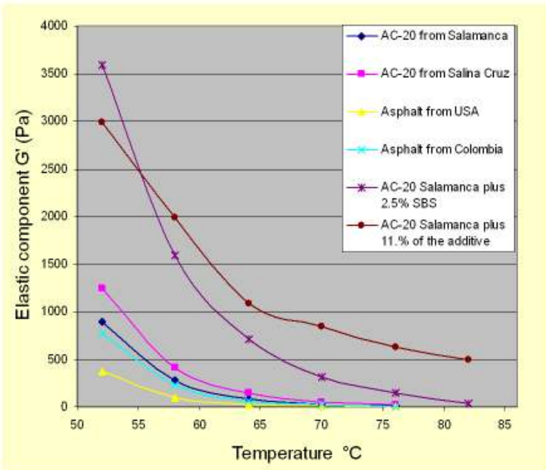
3.2. Results to show that the asphalt at temperatures between 58 y 82°C has the consistence of viscous fluid.

The figure 9 shows that the asphalt at temperatures between 58 and 82°C has the consistence of viscous liquid reducing rutting resistance of the pavement, but using 11.0% of the additive propose in this study this problem was reduced, because the additive increase the asphalt viscosity like the common of the polymers do, so, the ideal asphalt performance at this temperatures was obtained.



“Figure 9 - Increment viscosity of the asphalt AC-20 plus 11.0% additive at the temperatures between 58 and 82°C”.

Increasing the asphalt viscosity at the temperatures between 58 and 82°C this weakness of the asphalt is reduced, but is more important than the asphalt has a bigger elastic component and a smaller phase angle (δ) obtaining and smooth and elastic asphalt. The additive propose in this study gives to the asphalt this elastic properties. The figure 10 shows that using 11.0% of the additive in the asphalt AC-20 from Salamanca, the elastic component G’ has a high value at the temperatures between 58 y 82°C reducing rutting in the pavements and also a PG of 82 was obtained.

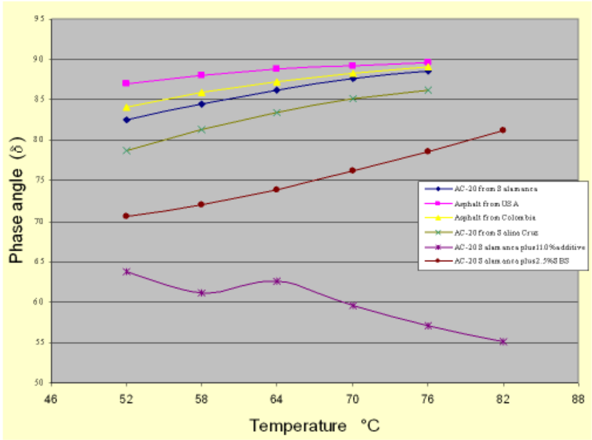


Asphalt AC-20 from Salamanca plus 11.0% of additive

Temperature (°C)	G* / sen δ (KPa)	Phase angle δ	G' (Elastic component) (Pa)	G'' (Viscous component) (Pa)	G* 0 (KPa)
Results before RTFO test					
52	7.556	63.81	2992	6084	6.7803
58	4.697	61.09	1988	3600	4.1117
64	2.638	62.55	1079	2078	2.3410
70	1.924	59.57	840.2	1430	1.6590
76	1.378	57.07	628.6	970.4	1.1566
82	1.044	55.17	489.5	703.5	0.8570
Results after RTFO test					
52	23.42	66.63	8528	19740	21.500
58	12.52	66.38	4596	10510	11.470
64	7.484	65.34	2838	6180	6.801
70	5.172	62.22	2133	4048	4.576
76	3.481	60.84	1481	2654	3.040
82	2.322	59.12	1022	1710	1.9928

“Figure 10 - High value of the Elastic component of the asphalt with 11.0% of the additive at temperatures between 58 and 82°C. A PG grade value of 82 was obtained”.

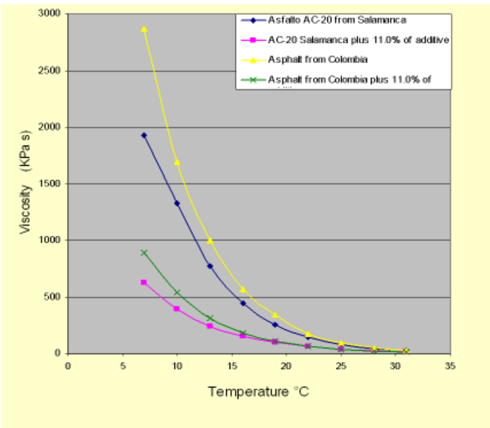
The figure 11 shows the special performance in the asphalt of the phase angle (δ) using 11.0% of the additive propose in this study, the phase angle decrease at the temperature between 58 and 82°C and the asphalt become very elastic. Normally all the asphalts (modified or not modified) increase their phase angle with the temperature (this is the reason because why the asphalt has the consistence of viscous liquid) and the pavement has a low rutting resistance.



"Figure 11 – Special performance in the asphalt of the phase angle (δ) using 11.0% of the additive proposes in this study in the temperature range from 52 to 82°C".

3.3. Results to show that Asphalt at low temperatures can be brittle

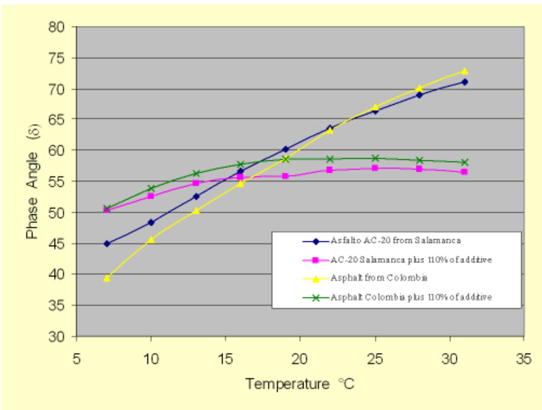
When the elastic component is higher than the viscous component, the phase angle (δ) decrease and the viscosity increase, as a result the asphalt become to be brittle. The figure 12 shows the viscosity of the asphalts from Mexico and Colombia at the temperatures between 7 and 31°C and using 11.0% of the additive the viscosity of booth asphalts is reduced obtaining the ideal asphalt performance at low temperatures.



	Viscosity KPa s			
Temperature °C	AC-20 Salamanca	AC-20 Salamanca + 11.0% additive	AC-20 Colombia	AC-20 Colombia + 11.0% additive
31	26.47	17.66	28.75	16.15
28	46.29	26.14	51.69	25.09
25	81.25	39.21	94.46	39.92
22	142.6	64.3	178.1	65.12
19	259.1	105.2	342.1	112.8
16	446.4	156.3	569.3	185.1
13	775.3	240.5	1000	316.1
10	1325	391.8	1693	542.7
7	1925	630.4	2868	887

Figure 12.- Asphalt reduction viscosity at low temperatures using 11.0% of the additive of the asphalt from Colombia and Mexico".

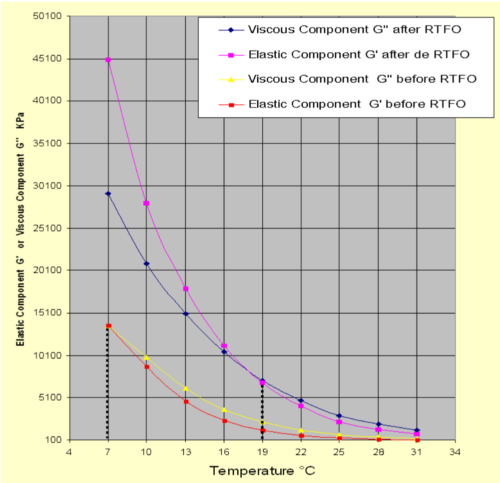
Using 11.0% of the additive the phase angle (δ) is higher than the normal asphalt and at low temperatures the asphalt becomes a smooth and elastic resistant to cracking at low temperatures, the figure 13 shows this effect.



"Figure 13 - High value of the Phase Angle (δ) at low temperatures using 11.0% of additive of the asphalts from Colombia and Mexico".

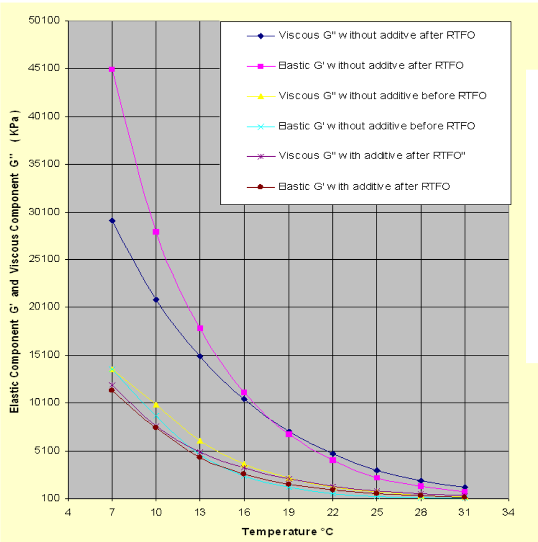
3.4. Results to show that Asphalt reacts with oxygen.

Oxidation causes the asphalt cement to become more brittle and the cracking problems happened in the pavement. The asphalt becomes to be brittle when the elastic component is higher than the viscous component, when the phase angle (δ) decrease and when the viscosity increase. The figure 14 shows the temperature when the viscous component and the elastic component have the same value at 7°C in the original asphalt and when this asphalt is oxidized using the RTFO test, the viscous component and the elastic component have the same value at 19°C, this temperature gradient from 7 to 19°C is an indicator that the asphalt is more brittle after oxidation.



"Figure 14 - Temperature of AC-20 from Salamanca when the elastic and viscous components have the same value after and before RTFO test".

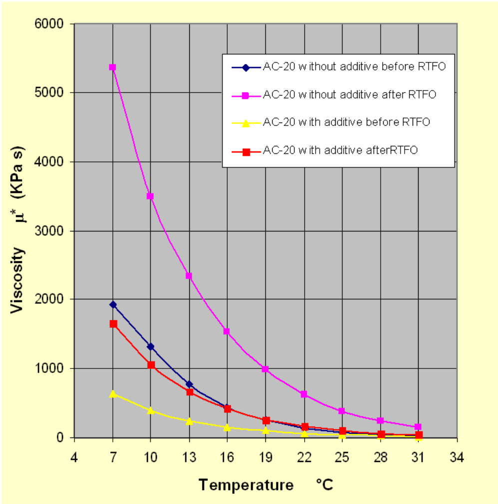
The addition of 11.0% the additive propose in this study to the asphalt AC-20 from Salamanca reduce the oxidation of the asphalt, the figure 15 shows this effect, where the viscous component and the elastic component of the asphalt AC-20 from Salamanca plus 11.0% of additive after RTFO test have the same value at the temperature of 7°C, and the temperature when the elastic and viscous components of this asphalt without additive after RTFO test have the same value is 19°C and before RTFO is 7°C, this means that the asphalt with the 11.0% of the additive begins its live in the pavement like the normal asphalt without has have the mixing and compaction process, this is a big advantage because the main oxidation of the asphalt happens in during the mixing and compaction process.



	AC-20 Salamanca before RTFO		AC-20 Salamanca after RTFO		AC-20 Salamanca + 11.0% additive after RTFO	
Temperature (°C)	Viscous Component G'' KPa	Elastic Component G' KPa	Viscous Component G'' KPa	Elastic Component G' KPa	Viscous Component G'' KPa	Elastic Component G' KPa
31	250.4	85.8	1266	781.2	366.6	233.9
28	431.8	166.8	1983	1359	562.4	365.9
25	744.5	325.3	3002	2280	854	573.8
22	1277	634.2	4785	4096	1349	950
19	2248	1288	7144	6830	2119	1585
16	3727	2456	10500	11230	3263	2629
13	6160	4707	14990	17920	4991	4405
10	9897	8806	20940	28020	7640	7483
7	13590	13628	29220	45000	12000	11426

"Figure 15 - Temperature of AC-20 from Salamanca with and without additive when the elastic and viscous components are the same after and before RTFO test".

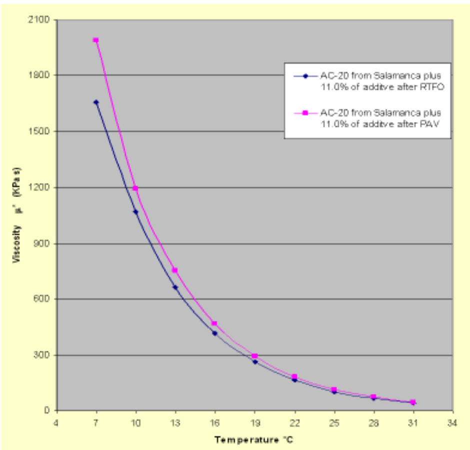
With the asphalt oxidation during the mixing and compaction process, the asphalt becomes to be brittle increasing its viscosity at low temperature, the figure 16 shows the asphalt viscosity at low temperature of the normal asphalt AC-20 from Salamanca before and after RTFO test and the asphalt viscosity at low temperature using 11.0% of the additive propose in this study. The viscosity of the asphalt with 11.0% of additive after RTFO is lower than the normal asphalt before RTFO, this means that the additive resolve the oxidation of the asphalt during mixing and compaction process.



	Viscosity KPa s			
Temperature °C	AC-20 Salamanca before RTFO	AC-20 Salamanca + 11.0% additive before RTFO	AC-20 Salamanca after RTFO	AC-20 Salamanca + 11.0% additive after RTFO
31	26.47	17.66	148.8	43.49
28	46.29	26.14	240.4	67.1
25	81.25	39.21	377	102.9
22	142.6	64.3	629.8	165
19	259.1	105.2	988.3	264.6
16	446.4	156.3	1537	419
13	775.3	240.5	2337	665.7
10	1325	391.8	3498	1069
7	1925	630.4	5365	1657

"Figure 16 - Viscosity of the Asphalt AC-20 from Salamanca with and without additive before and after RTFO test at low temperatures".

One standard practice for accelerated aging of asphalt is using a Pressurized Aging Vessel (PAV), this practice provides a means for simulating the long-term in service oxidative aging of asphalt. Using 11.0% of the additive propose in this study, the long-term in service oxidative aging of asphalt is reduced because the asphalt viscosity after RTFO test is very similar than the asphalt viscosity after PAV. The creep stiffness was evaluated after PAV and a PG of –22 was obtained; the figure 17 shows these results.



Asphalt AC-20 from Salamanca plus 11.0% of additive
PG 82-22

Creep Stiffness, m-value @ 60s -12ºC AASHTO T313 = 0.362
Creep Stiffness, m-value @ 60s -16ºC AASHTO T313 = 0.313
Creep Stiffness, m-value @ 60s -18ºC AASHTO T313 = 0.292

"Figure 17 - Viscosity of the Asphalt AC-20 from Salamanca plus 11.0% of additive after RTFO and after PAV at the temperatures between 7 and 31°C".

It is important to consider that all the oxidation tests were made according with method AASHTO T 240-06 "Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt, Rolling Thin Film Oven Test (RTFO)", that simulate the hardening that occurs during the mixing and compaction of hot mix asphalt. The temperature for this test is 163°C ± 1°C, but using 11.0% of the additive the mixing and compaction temperature never will be these, because the additive reduces these temperatures (table 2), for this reason the asphalt oxidation in the field will be lower than the results showed in this study.

3.5. Results to show that the asphalt does not have affinity with the aggregate and a high interfacial tension is generated.

The figure 18 shows the high interfacial tension in the surface between the asphalt AC-20 from Salamanca and a basaltic aggregate using the test ASTM D-3625, using 11.0% of the additive propose in this study, this high interfacial tension was reduced.

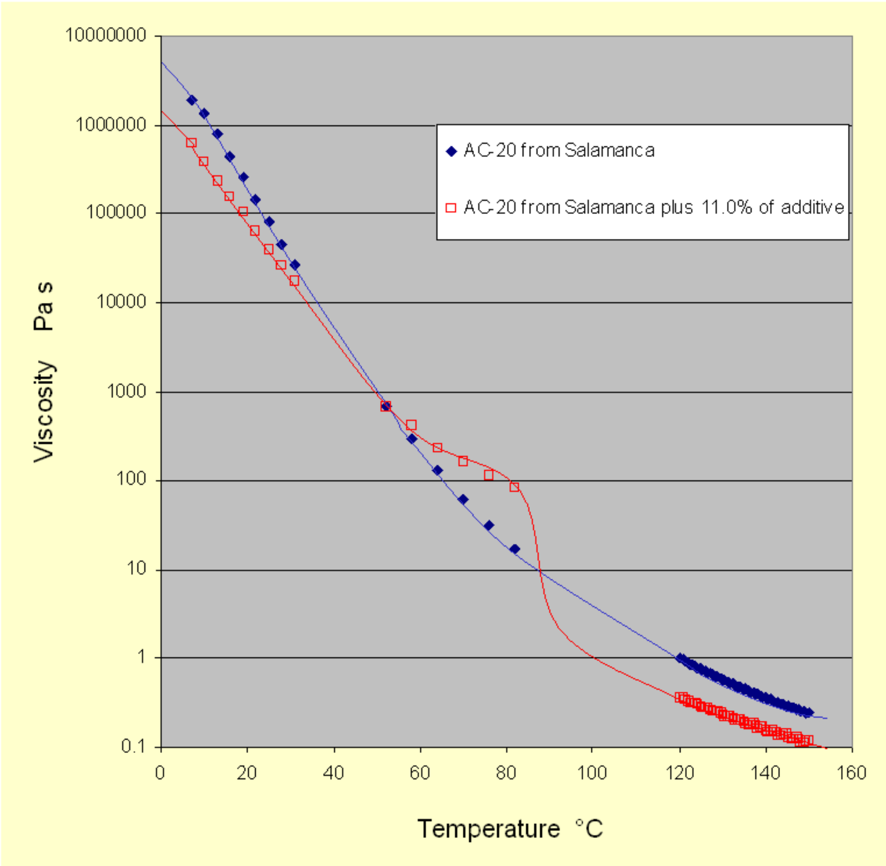

AC-20 from Salamanca


AC-20 from Salamanca plus 11.0% of additive

"Figure 18 - Effect of the additive in the reduction of the high interfacial tension between the asphalt and basaltic aggregate using the test ASTM D-3625".

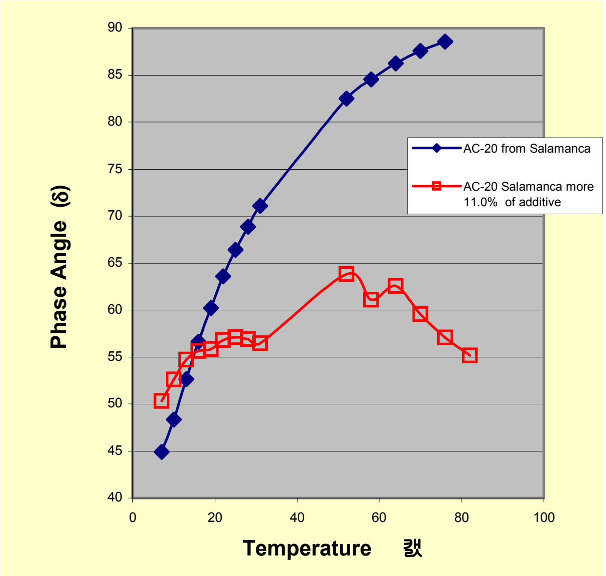
3.6. Results that show the ideal performance of the asphalt AC-20 from Salamanca.

To show the ideal asphalt performance of the asphalt AC-20 from the refinery of Salamanca using 11.0% of the additive propose in this study, the data of the tables 1 and 2 (reduction of the asphalt viscosity at the temperatures between 120 and 150°C), the data of the figure 9 (increment of the asphalt viscosity at the temperatures between 58 and 82°C) and the data of the figure 12 (reduction of the asphalt viscosity at the temperatures between 7 and 31°C) were saved and collocated in the graphic showed in the figure 19.



"Figure 19 - The ideal performance of the asphalt AC-20 from the refinery of Salamanca using 11.0% of additive".

Using the 11.0% of the additive propose in this study, a special asphalt was obtained showing an ideal performance and a smooth and elastic performance in the range of temperature between 0 and 82°C (the common polymers become a elastic and hard asphalt) due to the phase angle (δ) changes a few in this range of temperature and the phase angle of normal asphalt change so much decreasing the asphalt elasticity at high temperatures and increasing the asphalt hardening at low temperatures. This effect is the principal innovation of this study and is showed in the figure 20.



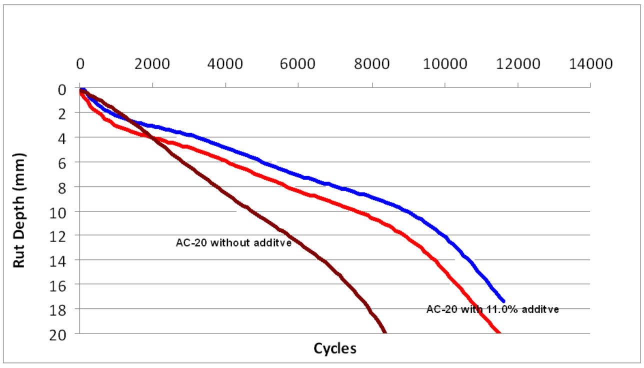
"Figure 20 – Phase Angle (δ) performance of the asphalt AC-20 from Salamanca with and without additive in the temperature range between 7 and 82°C".

3.7. Field Applications.

In the city of Guadalajara, Jalisco, Mexico, field applications were made in some streets following the Marshall design showed in the figure 7, which specified 6.5% of asphalt respect to the aggregate, 4.0% of voids and a the value of density mix design was 2,380 kg/m^3. The figure 21 shows one this applications in the "Morelos" street, were the mixing temperature was between 135 and 130°C and the compaction temperature was between 95 and 115°C.

"Figure 21 - Field application in the "Morelos" street in the city of Guadalajara, Jalisco, Mexico".

Some specimens were extracted from this application and the values of the mix density were between 2,270 and 2,345 kg/m^3 (more than 95% of the design density) and these specimens were conditioned in the Hamburg test showing better performance than the specimens without additive, the figure 22 shows these results.



"Figure 22 – Rut depth results using Hamburg test of the specimens extracted from the application in the Morelos Street ".

4. CONCLUSIONS

The conclusions using the Asphalt AC-20 from the Salamanca Mexico refinery plus 11.0% of the additive propose in this study are the following:

- The ideal asphalt performance was obtained reducing the asphalt viscosity at the temperatures between 100 and 150°C (tables 1 & 2 and figures 5, 6 & 19), increasing the asphalt viscosity at the temperatures between 58 and 82°C (figures 9 & 19) and reducing the asphalt viscosity at the temperatures between 4 to 31°C (figures 12 & 19).
- Due to the minimum variations of the phase angle (δ) in the range of temperature between 7 and 82°C a smooth and elastic asphalt performance was obtained (figures 11, 13, & 20). This ideal asphalt will be more elastic at the temperatures between 58 and 82°C and will be soft at the temperatures lower than 20°C.
- The five weakness of the asphalt were reduced, specially the asphalt oxidation during mixing and compaction process, due to after the RTFO test, the viscosity of this ideal asphalt is less than viscosity of asphalt without additive before RTFO (figure 16) and too that after RTFO test, the components elastic and viscous of this ideal asphalt are the same at the temperature of 7°C and with asphalt without additive these components are the same at 19°C after RTFO (figure 15), this means that ideal asphalt will begin the service life in the pavement like had been used a cold mix made with normal asphalt but with the compaction benefits of a hot mix.
- According with the standard specification for "Performance-Graded Asphalt Binder AASHTO M320", an eco-friendly asphalt with a grade PG 82 –22 was obtained. Using this asphalt the hot mix can be compacted at temperatures between 95 and 115°C.
- Important contributions for the environment were obtained because less energy was necessary for make this asphalt PG 82-22 and less energy was necessary for mixing and compaction process and the durability of this asphalt in the pavement was increased.

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