Caracterización reológica avanzada de betunes tradicionales y modificados utilizados actualmente en Chile

Advanced rheological characterization of traditional and modified bitumens currently employed in Chile

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Resumen

El objetivo de esta investigación fue obtener una caracterización reológica y clasificación avanzada para un grupo de betunes asfálticos modificados y sin modificar utilizados actualmente en Chile. Estudiando seis betunes asfálticos, provenientes de tres empresas asfalteras del medio nacional. Cada empresa aportó con un betún tradicional y un betún modificado. Los tres betunes tradicionales clasificados como CA 24 y los tres modificados clasificados como 60-80 modificados con SBS. Se realizó la caracterización reológica utilizando un reómetro de corte dinámico y un reómetro de viga en flexión, para los betunes en estado original, envejecimiento primario (RTFOT) y envejecimiento secundario (PAV). Determinando para cada uno la clasificación por grado de desempeño, ensayo de fluencia y recuperación (creep and recovery), curvas maestras y diagramas de Black. Se realizó además una completa batería de ensayos tradicionales al total de los betunes asfálticos, para los tres niveles de envejecimiento mencionados. La caracterización reológica permitió determinar las propiedades fundamentales de los betunes a temperaturas altas, temperaturas intermedias y bajas temperaturas. Estas propiedades en conjunto con una adecuada zonificación climatológica de Chile, podrían ser utilizadas para confeccionar una especificación de betunes moderna para nuestro país. También se demostró que para que los ensayos tradicionales tengan alguna utilidad, deben ser realizados para las siguientes condiciones: altas temperaturas, temperaturas intermedias, bajas temperaturas, ligante original, ligante con envejecimiento primario (RTFOT) y ligante con envejecimiento secundario (PAV). Solamente cuando se realizan ensayos para todas las condiciones anteriores, es posible encontrar información y resultados que son comparables a los de Superpave.

Palabras Clave: Reología, betunes asfálticos, reómetro

Abstract

The purpose of this research was to achieve an advanced rheological characterization and classification for a set of modified and non-modified asphaltic bitumens currently employed in Chile. Six asphaltic bitumens were employed, which are locally produced by three asphalt manufacturer companies. Each company provided a traditional bitumen and a modified bitumen. The three traditional bitumens were classified as CA 24 and, SBS-modified bitumens were classified as 60-80. Rheological characterization tests were carried out by employing a dynamic shear rheometer and a bending beam rheometer on bitumens under original condition; primary ageing (RTFOT) and secondary ageing (PAV). Consequently, performance level, creep and recovery tests, master curves and Black's diagrams were determined for each bitumens. Besides, diverse and complete traditional tests were performed to the whole set of bitumens, in accordance to the aforementioned ageing levels. The rheological characterization enabled the determination of bitumen essential properties at high temperatures, intermediate temperatures and low temperatures. These properties together with an adequate climatologically zoning of Chile could be employed to elaborate an updated specification for bitumens in our country. It was also demonstrated that traditional tests are only useful if they are carried out under the following conditions: high temperatures, intermediate temperatures, low temperatures, original binder, primary aged binder (RTFOT) and secondary aged binder (PAV). Only by executing tests under the aforementioned conditions, it is actually possible to achieve information and results comparable to the ones provided by Superpave.

Keywords: Rheology, asphaltic bitumens, rheometer

1. Introduction

Asphaltic bitumen specifications in Chile are of an empirical nature and they consider measurements for an incomplete set of material properties (Code MINVU 2008, Delgadillo et al. 2009; Highways Manual 2010). Some essential material properties - which are not currently characterized - correspond to behavior at low temperatures, material secondary ageing and essential mechanical properties such as dynamic modulus and phase angle (Delgadillo et al., 2005, Delgadillo et al., 2006).

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Under the Fondef D09I1174 project framework: “Development of Asphaltic Resurfacing Materials Employed for Damaged Pavements Restoration”, The Federico Santa Maria University implemented an advanced laboratory characterization of bitumen and asphaltic mixes. The equipment employed in this work consists of a Dynamic Shear Rheometer, which was used together with the Bending Beam Rheometer for the advanced characterization of bitumens.

Bitumen characterization is one of the first stages in the project. Bitumens showing the best performance at this stage were selected for their utilization on asphaltic mixes characterization in the second stage, which is currently under execution.

2. Classification according to performance level (PG XX-YY) superpave

2.1 Test Conditions

Classification tests including all bitumens according to their performance levels, were developed by using the Dynamic Shear Rheometer (DSR) and by following the procedure described in section 8.302.00 of the Chilean Highways Manual, as well as the ASTM D7175-08 standard. Each asphaltic bitumen was tested under original condition and with primary ageing (RTFOT) and secondary ageing (PAV).

For bitumens under original conditions and primary ageing (RTFOT), test temperatures varied from 46°C to 82°C. For bitumens with secondary ageing (PAV), temperatures decrease in the course of the test; such temperature varies from 40°C to 4°C. Test frequency was established in 10[rad/s] by the Superpave standard.

The test stops when it achieves a $G^*/\sin(\delta)$ minimum parameter value and a $G^*\sin(\delta)$ maximum parameter value. G^* is the complex shear module and δ is the phase angle.

- Bitumen under normal conditions: $G^*/\sin(\delta) \geq 1$ [KPa]
- Bitumen aged with RTFOT: $G^*/\sin(\delta) \geq 2,2$ [KPa]
- Bitumen aged with PAV: $G^*\sin(\delta) \leq 5000$ [KPa]

The classification according to performance level at low temperatures was developed by employing the results achieved by the Bending Beam Rheometer (BBR) tests, which were carried out at the National Highway Administration's laboratory.

The classification for intermediate temperatures was obtained by means of the failure parameter $G^*\sin(\delta)$ for bitumens with secondary ageing (PAV).

The classification at high temperatures was obtained by means of the failure parameter criteria $G^*/\sin(\delta)$ for bitumens under original conditions and with primary ageing (RTFOT), considering the most conservative case between them.

The Table 1 shows the classification according to performance level, considering the exact value where failure criteria and the approximate value specified in the section 8.301.8 of Highways Manual are met. It also shows the intermediate temperatures for bitumens with secondary ageing (PAV) and the expected pavement temperature,

which is obtained by means of the semi sum between the minimum, and maximum temperature plus 4°C.

Table 1. Classification Results according to performance level

Datos del Betún/ Bitumen Information			Clasificación Superpave/ SuperPave Classification				Temperatura Intermedia/ Intermediate temperature [°C]	
Betún Asfáltico / Asphaltic bitumens	Tipo de Betún / Type of Bitumens	Empresa / Manufacturer	MC 8.301.8		Exacta/ Exact		De cumplimiento del parámetro de Fatiga / Fatigue fulfillment parameter	Requerida por Superpave / Required by SuperPave
			PG-XX	PG-YY	PG XX	PG YY		
CA 24	Tradicional Traditional	1	64	-22	67	-23	23	26
CA 24	Tradicional Traditional	2	64	-22	69	-26	23	26
CA 24	Tradicional Traditional	3	64	-22	67	-23	22	26
60-80	Modificado Modified	1	70	-22	74	-27	21	28
60-80	Modificado Modified	2	70	-28	74	-29	16	27
60-80	Modificado Modified	3	70	-22	75	-27	20	28

2.2 Classification Comments on Superpave Performance Level

It is observed that these three traditional bitumens have the same classification in accordance with the categories defined by the Highways Manual. However, the exact results of specifications fulfillment indicate that bitumen II shows a lower thermal susceptibility and it has a greater stiffness at high temperatures and, lower fluidity at low temperatures. Fulfillment temperatures for intermediate temperatures are quite similar for the three bitumens.

Modified bitumes also maintain such slight difference, where bitumen II has the lowest thermal susceptibility. In regards to intermediate temperatures, bitumen II shows a far lower temperature of parameter fulfillment compared to the other two modified bitumens, which might be an indicator of better bitumen II performance against pavement cracking at intermediate temperatures.

By comparing traditional and modified bitumens it is possible to establish that: the highest temperature level achieved by modified bitumens is clear; in particular they have a higher failure temperature thus showing a better behavior against rutting failures. At low temperatures modified bitumens reach lower failure temperatures. Thermal susceptibilities are significantly lower for modified bitumens.

3. Master curves

Dynamic modulus is an essential property of asphaltic bitumen and asphaltic mixes. The latter is one of the most relevant input data for flexible pavements mechanistic design by means of the utilization of multi-layer elastic models (Wahr et al., 2008, Wahr et al., 2009). Up-dated estimation formulas used to calculate dynamic modulus (Christensen et al., 2003, Bari et al., 2006) employ the complex modulus to estimate the mix modulus. Master curves were developed for different bitumens, which were obtained from complex modulus tests at different temperatures and frequencies.

3.1 Test Conditions

Master curves were designed considering an asphaltic bitumen under normal conditions, with primary ageing (RTFOT) and secondary ageing (PAV). Frequency scans were carried out at temperatures ranging from 5 to 55°C, at intervals of 5°C. Thus frequency scans covered high temperatures as much as low temperatures. A frequency range was established considering it would not affect DSR and would enable us to obtain results without exposing the equipment to measurement errors.

A very low frequency (less than 0.1 [rad/seg]) takes a very long time before achieving the parameters results. On the other hand, a high frequency (above 100 [rad/seg]) provokes measurement errors, since the asphalt sample begins to disintegrate at low temperatures. That is the reason why frequencies were set within a range of [0.1- 73] [rad/seg].

The behavior of complex shear modulus (G^*) shows greater variations at low frequencies, but it tends to keep high frequencies. Therefore, each frequency scan was carried out at a logarithmic scale, in order to cover the greatest amount of low frequencies for measurements.

There are not requirements for stresses levels to be applied during a frequency scan test, excepting that they must be at an elastic range and they have to be executed at constant deformation. A temperature at 5°C, frequency at 10 [rad/seg] and a variable deformation range from 0.1% up to 100% were considered for these frequency scan tests. Consequently, traditional and modified asphaltic bitumens show a linear behavior up to 1% of deformation levels. That is the reason why a constant deformation of 0.5% was considered for frequency scan tests.

3.2 Elaboration of master curves

They were elaborated at a referential temperature of 20°C, shift-factors were manually determined for each temperature at a 5-55 [°C] range, every 5°C.

Figure 1 shows the master curves obtained for each one of the six asphaltic bitumens under original conditions at a logarithmic scale. Primary ageing (RTFOT) and secondary ageing (PAV) graphs are not shown due to space restrictions, but they can be obtained from the original research job (González, 2012).

Figure 1. Master Curve for bitumens under original conditions with G^* at logarithmic scale

3.3 Comments on Master Curves

Traditional bitumens I and III have a similar behavior, particularly when they have a secondary ageing (PAV). Besides, bitumen III has the highest thermal susceptibility. Bitumen II has high G^* values during a great portion of the analyzed frequency range, especially for frequencies lower than 100 [rad/seg].

Modified bitumens I and III have a similar behavior achieving G^* values quite similar for all analyzed temperatures.

The modified bitumen II stands out for having the less thermal susceptibility of all tested bitumens, which is an expected characteristic for asphalts.

The ageing on bitumens provokes an increase of stiffness on bitumens, which is observed with the increase of complex shear modulus (G^*). There is an outstanding difference when comparing G^* values with secondary ageing (PAV) to bitumens under normal conditions. The effect of primary ageing is less evident and in the case of traditional bitumen and modified bitumen III, it is practically insignificant.

4. Black's diagrams

Black's diagrams are phase angle graphs versus complex modulus. They are useful tools for identifying bitumens and modifier agent types. Besides, they enable the identification of potential measurement errors.

4.1 Test Conditions

Test conditions are the same as those employed for the elaboration of Master curves because both parameters are obtained from the same frequency scan. Black diagrams were elaborated considering bitumen under original condition, with primary ageing (RTFOT) and secondary ageing (PAV).

Temperatures considered for frequency scan vary from 5 up to 55°C, measuring every 5°C. Each frequency scan considered an initial frequency of 0.1[rad/seg] and final frequency of 73 [rad/seg]. There are not restrictions for applied stresses as it is the case for Master Curves. However this test must be carried out at constant deformation, which was established equal to 0.5%

4.2 Comments on Black's Diagrams

Black's Diagram satisfactorily fulfilled its purpose, because it was an effective tool for determining measurement errors (Marastenou et al., 2001, Airey et al., 2002) and it showed the effects of polymeric additives of modified bitumens.

The greatest measurement errors source was generated as a consequence of the geometry change of test rheometer (parallel plates of 8 and 25 mm), which is evidenced by observing the Black's Diagramming for Modified Bitumen mix 60-80 from manufacturer 2, under original conditions. It shows that developed measurements carried out with the 8mm-plate are vertically displaced in regards to measurements performed with the parallel 25mm-plate. An example is shown on Figure 2, where the change of test geometry generates a vertical distance indicated by Black's Diagram.

Figure 3 indicates that traditional bitumens generate soft curves, while modified bitumens produce irregular section curves. This situation is explained by the presence of a modifier polymer in such bitumens.

Figure 2. Black's Diagram for modified bitumen II under normal conditions

Figure 3. Black's diagramming for all bitumens under original conditions

5. Creep and recovery test

5.1 Test Conditions

A Dynamic Shear Rheometer (DSR) was employed, which carried out five measurements on each bitumen. This procedure was developed in accordance with ASTM D7405-10a standard. Tests were applied on primary ageing bitumens (RTFOT). This test was executed at a temperature of 64°C, which is considered representative of high temperatures.

In accordance with ASTM D7405-10a standard, the test consists of twenty intervals, each one having a loading cycle and an off-time cycle. The first ten intervals are executed by applying a stress of 100 [Pa] in each loading cycle, while for the following ten intervals a stress of 3200 [Pa] is applied during loading cycles.

Table 2 shows the results achieved by the creep and recovery test. Columns four and five show the creep compliance, which is not recoverable for bitumens.

Table 2. Summary of creep and recovery test results

Betún Asfáltico/ Asphaltic Bitumen mix	Resumen Creep and Recovery (valores promedios)/Summary of Creep and Recovery Test (average values)					
	R 0,1 [Kpa] [%]	R 3,2 [Kpa] [%]	Jnr 0,1 [Kpa] [1/Kpa]	Jnr 3,2 [Kpa] [1/Kpa]	R dif. %	Jnr dif. %
	Porcentaje de/ Recovery	Porcentaje de/ Recovery	Flexibilidad en/ Flexibility in	Flexibilidad en/ Flexibility in	Diferencia de/ Recovery	Diferencia de Flexibilidad/Flexibility difference
	recuperación/ percentage	recuperación/ percentage	fluencia no recuperable/non- recoverable creep	fluencia no recuperable/non- recoverable creep	recuperación/ difference	en fluencia no recuperable/non- recoverable creep
CA 24 Empresa/ Manufacturer (1)	3,65	0,46	2,60	2,86	87,53	9,89
CA 24 Empresa/ Manufacturer (2)	6,45	1,31	2,04	2,32	79,67	13,59
CA 24 Empresa/ Manufacturer (3)	3,38	0,06	2,93	3,26	98,27	11,13
60-80 Empresa/ Manufacturer (1)	38,77	20,03	0,71	1,03	48,13	44,95
60-80 Empresa/ Manufacturer (2)	68,28	62,12	0,39	0,50	9,06	26,93
60-80 Empresa/ Manufacturer (3)	51,79	34,14	0,51	0,77	34,03	51,24

Figure 4 shows the behavior of traditional and modified bitumen mixes.

Figure 4. Results of Creep and Recovery tests on traditional and modified bitumens

5.2 Comments on Creep and Recovery Test

There are no significant differences among traditional bitumens and, bitumen II is the one showing a slight better performance. However, there is a significant difference among modified bitumens, where bitumen mix II shows deformation levels lower than 50% compared to the deformation of bitumen I, which is the worst performance.

Modified bitumens show deformations significantly lower than traditional bitumens. This is mainly because of the existing deformation recovery taking place at off-time cycles, while traditional bitumens do not show such recovery.

6. Traditional tests

6.1 Test Conditions

Traditional tests were executed on the total amount of studied bitumens. In the case of traditional bitumens CA 24, they were tested under three different conditions: original condition, primary ageing (RTFOT) and secondary ageing (PAV). These three ageing stages of bitumen were considered because in this way it is possible to representatively characterize the behavior during the bitumen life span.

In the case of modified bitumens 60-80, modified with SBS, they are also tested under three different conditions: original condition, primary ageing (RTFOT) and secondary ageing (PAV). A storage stability test was also carried out for this bitumen type.

The results are shown on Table 3 and 4, respectively.

Table 3. Results from traditional bitumens

Betún Asfáltico Tradicional - CA 24/Traditional Bitumen Mix – CA 24					
N°/#	Ensayo/Test	Unidad/ Unit	Betún I/ Bitumen mix I	Betún II/ Bitumen mix II	Betún III/ Bitumen mix III
ORIGINAL – CA24					
1	Penetración a 25°C, 100gr, 5seg, 0,1mm/Penetration at 25°C, 100 gm, 5 sec, 0.1m	[dmm]	66	65	64
2	Penetración a 40°C/Penetration at 40°C	[dmm]	300	265	240
3	Ensayo de la Mancha [% Xilol]/Spot test (% Xilol)	[%Xilol]	<20	<30	<20
4	Ductilidad a 25°C, 5cm/min, [cm]/Bending performance at 25°C, 5cm/min, [cm]	[cm]	>150	>150	>150
5	Ductilidad a 15°C, 5cm/min, [cm]/Bending performance at 15°C, 5cm/min, [cm]	[cm]	>150	83	>150
6	Ductilidad a 5°C, 5cm/min, [cm]/Bending performance at 5°C, 5cm/min, [cm]	[cm]	3	1	1
7	Punto de Inflamación, [°C]/Flash point, [°C]	[°C]	316	324	301
8	Solubilidad en Tricloroetileno, [%]/Trichloroethylene Solubility, [%]	[%]	100,0	99,99	99,95
9	Viscosidad Cinemática a 135°C [Centistokes]/Cinematic viscosity at 135°C [centistokes]	[cSt]	445	518	408
10	Viscosidad Absoluta a 60°C, 300mm Hg, [poise]/Absolute viscosity at 60°C, 600 mm Hg, [poise]	[poise]	2729	3029	2575
11	Punto de Ablandamiento, [°C]/Yielding point, [°C]	[°C]	48,6	49,8	49,0
12	Punto de Fragilidad de Fraas/Fraas brittle point	[°C]	-11	-13	-14
13	Índice de Penetración/Penetration index	IP	-0,9	-0,6	-0,9
RTFOT – CA24					
14	Penetración a 25°C, 100gr, 5seg, 0,1mm/Penetration at 25°C, 100 gm, 5 sec, 0.1m	[dmm]	36	37	43
15	Ductilidad a 25°C, 5cm/min, [cm]/Bending performance at 25°C, 5cm/min, [cm]	[cm]	>150	103	>150
16	Ductilidad a 15°C, 5cm/min, [cm]/Bending performance at 15°C, 5cm/min, [cm]	[cm]	24	11	85
17	Ductilidad a 5°C, 5cm/min, [cm]/Bending performance at 5°C, 5cm/min, [cm]	[cm]	1	0	0
18	Punto de Ablandamiento, [°C]/Yielding point, [°C]	[°C]	53,4	55,6	52,0
19	Variación Punto de Ablandamiento, [°C]/Variation of yielding point [°C]	[°C]	4,8	5,8	3,0
20	Punto de Fragilidad de Fraas/Fraas brittle point	[°C]	-11	-10	-14
21	Pérdida por Calentamiento, Variación Masa [%]/Loss due to heating, Mass variation [%]	[%]	0,02	0,08	0,02
22	Viscosidad Absoluta a 60°C, 300mm Hg, [poise]/Absolute viscosity at 60°C, 300 mm Hg, [poise]	[poise]	6521	8938	5929
23	Índice de Durabilidad/Durability index	ID	2,4	3,0	2,3
23	Penetración, ([%] del original)/Penetration ([%] of the original)	[%]	54,5	56,6	67,2
PAV CA24					
24	Penetración a 25°C, 100gr, 5seg, 0,1mm/Penetration at 25°C, 100 gm, 5 sec, 0.1m	[dmm]	19	22	25
25	Ductilidad a 25°C, 5cm/min, [cm]/Bending performance at 25°C, 5cm/min, [cm]	[cm]	44	22	130
26	Ductilidad a 15°C, 5cm/min, [cm]/Bending performance at 15°C, 5cm/min, [cm]	[cm]	6	4	6
27	Ductilidad a 5°C, 5cm/min, [cm]/Bending performance at 5°C, 5cm/min, [cm]	[cm]	0	0	0
29	Viscosidad Absoluta a 60°C, 300mm Hg, [poise]/Absolute viscosity at 60°C, 300 mm Hg, [poise]	[poise]	31667	31117	21733
29	Punto de Ablandamiento, [°C]/Yielding point, [°C]	[°C]	61,6	64,0	58,2
30	Punto de Fragilidad de Fraas/Fraas brittle point	[°C]	-7	-3	-9

6.2 Comments on tradition Tests

The results obtained for traditional bitumens established that penetration at 25°C (under original conditions, analysis performed at intermediate temperatures) is quite similar, because I, II and III bitumens have a similar penetration level showing differences of only 2 dmm, between the highest and lowest temperature. Contrarily, bending performance at 15°C delivers differences, because the bitumen II value is much lower in comparison to the two others. According to (Kandhal 1977) standard, it would indicate a potential lower fatigue cracking performance throughout time. By analyzing absolute viscosity at high temperatures, it can be observed that three bitumens are within a viscosity range of 3000 ± 600 poises, which is the specified viscosity for an AC 30 according to the ASTM D3381-05 standard. As far as yielding point is concerned, the three bitumens showed similar values, with variations of 1°C between the highest and the lowest of them.

Table 4. Results from modified bitumens

Betún Asfáltico Modificado 60-80/Modified Bitumen Mix – 60-80					
Nº/#	Ensayo/Test	Unidad/ Unit	Betún I/Bitumen mix I	Betún II/Bitumen mix II	Betún III/ Bitumen mix III
Original - Betún Asfáltico Modificado 60-80/ Original - Modified Bitumen Mix – 60-80					
1	Penetración a 25°C, 100g, 5s, 0,1mm/Penetration at 25°C, 100 gm, 5 sec, 0.1mm	[dm]	62	77	64
2	Ductibilidad a 25°C, 5cm/min, [cm]/Bending performance at 25°C, 5cm/min, [cm]	[cm]	118	110	124
3	Ductibilidad a 15°C, 5cm/min, [cm]/Bending performance at 15°C, 5cm/min, [cm]	[cm]	>150	100	136
4	Ductibilidad a 5°C, 5cm/min, [cm]/Bending performance at 5°C, 5cm/min, [cm]	[cm]	44	58	51
5	Punto de Inflamación, [°C]/Flash point, [°C]	[°C]	309	315	307
6	Punto de Ablandamiento, [°C]/Yielding point, [°C]	[°C]	69,9	68,0	68,8
7	Punto de Fragilidad de Fraas/Fraas brittle point	[°C]	-17	-22	-17
8	Recuperación Elástica, 13°C [%]/Elastic recovery, 13°C [%]	[%]	88	87	87
9	Recuperación Elástica, torsión,25°C, [%]/Elastic recovery from tensile stress, 25°C, [%]	[%]	62	79	71
10	Recuperación Elástica, torsión,40°C, [%]/Elastic recovery from tensile stress, 40°C, [%]	[%]	48	73	45
11	Índice de Penetración/Penetration index	IP	3,3	3,8	3,3
12	Perfil Viscosidad Rotacional (135/150/170/190°C)/ Rotational viscosity profile (135/150/170/190°C)	[poise]	135/150/170/190 12,6/5,43/2,55/1,29	135/150/170/190 18,06/8,82/4,36/2,42	135/150/170/190 1141/523/255/130
Estabilidad al Almacenamiento / STORAGE STABILITY					
13	Viscosidad Rotacional (170°C), Superior/Inferior/Rotational viscosity (170°C). Highest/lowest	[poise]	2,33 / 2,33	4,56 / 4,59	240 / 240
	Ensayo de Separación (Dif. Visc. Rotacional 170°C)/Separation test (Dif. Rotational Viscosity 170°C)	[%]	0	0,7	0,2
14	Punto de Ablandamiento, [°C]. Superior/Inferior/Yielding point, [°C]. Highest/lowest	[°C]	56,0 / 56,2	69,0 / 69,8	55,8 / 55,5
	Diferencia Punto de Ablandamiento/Yielding point difference	[°C]	0,2	0,8	0,3
15	Penetración a 25°C, 100g, 5s, 0,1. Superior/Inferior/Penetration at 25°C, 100 gm, 5 sec, 0.1mm. Highest/lowest	[dm]	59 / 59	75 / 75	60 / 56
	Diferencia Penetración/Penetration difference	[dm]	0	0	4
RTFOT - Betún Asfáltico Modificado 60 -80 / RTFOT – MODIFIED ASPHALT MIX 60-80					
16	Variación de la Masa/Mass variation [%]	[%]	0,03	0,04	0,03
	Penetración a 25°C, 100gr, 5seg, 0,1mm/Penetration at 25°C, 100 gm, 5 sec, 0.1mm	[dmm]	44	61	43
17	Variación Penetración a 25°C/Penetration variation at 25°C, [%]	[%]	71	79	67
18	Ductibilidad a 25°C, 5cm/min, [cm]/Bending performance at 25°C, 5cm/min, [cm]	[cm]	108	95	101
19	Ductibilidad a 15°C, 5cm/min, [cm]/Bending performance at 15°C, 5cm/min, [cm]	[cm]	105	65	87
20	Ductibilidad a 5°C, 5cm/min, [cm]/Bending performance at 5°C, 5cm/min, [cm]	[cm]	23	30	19
21	Punto de Ablandamiento, [°C]/Yielding point, [°C]	[°C]	65,6	63,6	66,7
	Variación Punto de Ablandamiento, [°C]/Yielding point variation, [°C]	[°C]	-3,4	-4,4	-2,1
22	Recuperación Elástica, 13°C [%]/Elastic recovery, 13°C [%]	[%]	83	83	82
23	Recuperación Elástica, torsión, 25°C, [%]/Elastic recovery from tensile stress, 25°C, [%]	[%]	64	72	67
24	Recuperación Elástica, torsión, 40°C, [%]/Elastic recovery from tensile stress, 40°C, [%]	[%]	56	57	58
25	Punto de Fragilidad de Fraas/Fraas brittle point	[°C]	-13	-20	-15
PAV - Betún Asfáltico Modificado 60 - 80 / PAV – MODIFIED ASPHALT MIX 60-80					
26	Penetración a 25°C, 100gr, 5seg, 0,1mm/Penetration at 25°C, 100 gm, 5 sec, 0.1mm	[dmm]	26	29	22
27	Ductilidad a 25°C, 5cm/min, [cm]/Bending performance at 25°C, 5cm/min, [cm]	[cm]	66	33	75
28	Ductilidad a 15°C, 5cm/min, [cm]/ Bending performance at 15°C, 5cm/min, [cm]	[cm]	32	24	45
29	Ductilidad a 5°C, 5cm/min, [cm]/ Bending performance at 5°C, 5cm/min, [cm]	[cm]	6	7	5
30	Punto de Ablandamiento, [°C]/Yielding point, [°C]	[°C]	65,6	69,0	68,7
31	Recuperación Elástica, 13°C [%]/Elastic recovery, 13°C [%]	[%]	71	74	68
32	Recuperación Elástica, torsión, 25°C, [%]/Elastic recovery from tensile stress, 25°C, [%]	[%]	35	54	37
33	Recuperación Elástica, torsión, 40°C, [%]/Elastic recovery from tensile stress, 40°C, [%]	[%]	42	75	59
34	Punto de Fragilidad de Fraas/Fraas brittle point	[°C]	-9	-15	-11

For the primary ageing condition (RTFOT) at intermediate temperatures, penetrations at 25°C show greater differences than for original bitumens, with variations of 7dmm between the softest (bitumen III, 43dmm) and the hardest (bitumen I, 36 dmm), but always within a low range. Bending performance at 15°C is still within an acceptable range for bitumens I and III, but quite lower for bitumen II, which value is at 11. The latter value indicates a high cracking susceptibility in a near future for bitumen II, considering that a value lower than 10 is considered as negative (Kandhal 1977).

In secondary ageing condition (PAV), penetration differences are also quite similar to RTFOT condition. Once again bending performance of bitumen II happens to be the lowest, delivering a value of 4, which in accordance to the existing literature (Kandhal 1977) indicates there is a relevant cracking risk. The other two bitumens have a bending performance equal to 6 at 15°C, which would indicate some surface material loss risk at older pavement ages.

Fraas brittle point at low temperatures for bitumen II is 6°C higher than bitumen III, 4°C higher than bitumen I, thus showing a potential worse performance at low temperatures.

From three traditional bitumen mixes, the bitumen mix III showed the lowest ageing levels, which is evidenced by the three held back penetrations and durability indexes.

Modified bitumens under original conditions indicate that for intermediate temperatures, the bitumen II happens to be the softest, close to 80 dmm, in accordance with penetrations obtained at 25°C; while the other two bitumens are close to 60 dmm. Bending performance at 15°C for bitumen II is once again lower than the two other bitumens.

Under primary ageing condition (RTFOT) for intermediate temperatures, the penetration at 25 °C of bitumen II is once again significantly higher, exceeding by 17 and 18 dmm the other bitumen mixes. Bending performance at 15°C of bitumen II is lower than the others. At low temperatures, the bitumen II has the lowest value of Fraas brittle point. At high temperatures it was found that the yielding point is similar for the three bitumens.

Under secondary ageing condition (PAV) for intermediate temperatures, penetration indicates that bitumen II is the softest. For bending performance at 15°C, the bitumen stands for having the highest value of all bitumens, although according to Kendal's standard the three bitumens have a satisfactory behavior.

For Fraas brittle point, the bitumen II has a value 5°C lower than the other two bitumens, thus showing a better potential behavior at low temperature.

By comparing results between traditional and modified bitumens, it can be concluded that penetration levels do not greatly differ for the original condition of the six bitumens. However, there are remarkable differences at high and low temperatures, where modified bitumens have significantly lower thermal susceptibility. By ageing modified bitumens, they maintain the highest bending performance values, which might indicate a better fatigue cracking resistance.

7. Conclusions

The SuperPave performance characterization enabled the determination of essential properties (complex modulus and phase angle) of bitumens at high temperatures, intermediate temperatures and low temperatures. The three traditional bitumens were classified as PG64-22. Two modified bitumens were classified as PG70-22 and one as PG70-28. However, such difference is not quite significant if the exact temperatures of fulfillment parameters in the specification are considered, instead of the proposed discrete categories (-27 y -29°C, respectively). These PG classifications levels, together with a proper climatologically zoning of Chile could be used to elaborate an up-dated bitumens specification for our country.

Master curves elaborated for each bitumens enables the determination of binders stiffness and elasticity at any temperature and loading frequency combination. The complex model of each bitumen can be used, for example, for the estimation of the dynamical modulus of the asphaltic layer in pavement designs by means of elastic multi-layers programs. The master curves also enabled the visualization of thermal susceptibility for modified bitumens.

Black's diagrams became a very useful tool for starting up the dynamic shear rheometer, because they enabled the development of data analysis and the detection of measurement errors, which were consequently corrected. Besides, by means of these diagrams it was possible to detect the use of SBS modifier agent in modified binders.

Creep and recovery tests enabled us to witness relevant existing elasticity differences between traditional and modified bitumens, when they were subject to repetitive loads, such as road pavement traffic loads. This elastic recovery turns into less permanent deformations on modified bitumens at high temperatures.

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