Calprene®

Solprene®

Pavement

Technical bulletin

Dynasol

Dynasol - PAVEMENT - Technical bulletin

This technical bulletin on Pavement has been prepared by our highly qualified team of technical experts in order to help our customers to understand what our products have to offer and to share our know-how.
Our Technical Assistance and Development department is constantly working:

- Alongside our clients supporting them every step of the way.
- To maintain the quality and competitivity of our products and provide a high quality technical service.
- To locate possible new markets and clients through the development of new products and services or by improving existing products.

With its Madrid Technology Center and application laboratories in Santander and Altamira, Dynasol offers the market the benefits of a group of highly qualified specialists and a product catalogue of more than 40 products; many of which were developed over the last few years.

The main properties of are calprene thermoplastic rubbers are that they are well suited to the production of binding mixtures for road paving, due to their ability to modify bitumen effectively and to enhance properties they confer. They are of particular interest for long lasting thin-layer wearing courses and draining wearing courses, whose tough service conditions demand the highest technical standards.

Dynasol's elastomers are globally positioned as an excellent all-weather solution for increasing the strength of asphalt emulsions for roads and highways.

The asphalt cover or pavement of a road may be described in simple terms as a combination of aggregates of chippings together with bitumen, the latter acting as a binder. The chippings are granules of varied composition, such as siliceous and calcareous minerals, exhibiting different particle size distributions. Chippings are the main component of asphalt pavements and account for approximately 95% of the mixture.

The bituminous pavement of roads usually consists of three layers: a bituminous sub-base, an intermediate layer or road-base, and a surface (Fig. 1).

The structural design of a pavement must efficiently distribute the stresses and strains caused by road traffic, and the materials used must also be capable of conforming to a wide range of mechanical and other demands. The thickness and rigidity of the different layers are very important factors; in general, the rigidity of each layer is greater than the one directly beneath it.

The mechanical loads are caused by the contact of vehicle wheels with the pavement. The structural design of any pavement is determined by the maximum axle load (that part of a vehicle's total weight distributed on each axle) and the maximum traffic frequency the road is expected to withstand.

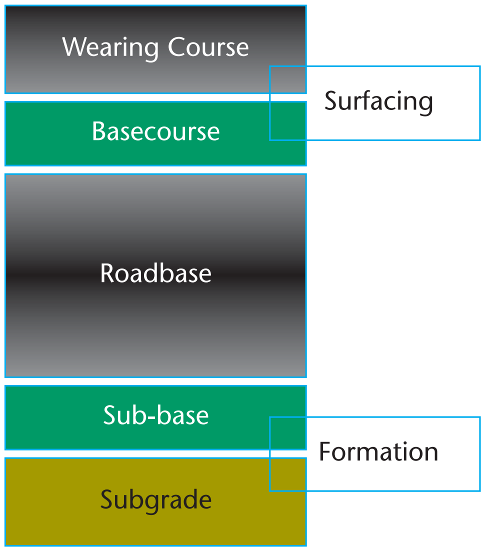


Figure 1. **Schematic Pavement structure consisting of three layers**

The bituminous sub-base constitutes the foundation on which the pavement is laid. It is the deep-most layer and is placed directly onto the compact ground or subgrade. It is the working platform onto which the other layers are subsequently laid. It serves as an insulating layer that protects the subgrade from water and freezing.

The intermediate or road-base layer is the main structural element of the pavement. Its main function is to distribute the loads and prevent localised overloading. It is made up of dense bituminous aggregates and must be capable of withstanding all loads, including stresses caused by temperature changes, and prevent permanent deformation and fatigue cracks.

The surface is made up of two sub-layers: base-course and wearing course. The base-course is placed directly onto the road-base and is approximately 6 cm (2,5 inches) thick. Its function is to distribute the traffic load onto the road-base, as well as provide a good surface onto which to lay the wearing course.

There are multiple technical requirements for the wearing course: contribution to the structural strength of the pavement, impermeability to air, rain, ice, etc. to protect the lower layers, as well as resistance to strain under load, the environment, fatigue, abrasion, etc.

Two types of surfacing of particular interest are the long-lasting thin-layer wearing courses and the porous wearing courses.

The long-lasting thin-layer wearing courses are aggregates of chippings with discontinuous particle size distribution and bituminous binder. This type of wearing course gives good wheel adhesion onto the pavement as well as decreasing the level of noise. Even though the longlasting thin-layer wearing course is just 2 to 3 cm (approx. 1 inch) thick, it must provide, among other things, high resistance to fatigue and plastic deformation.

The porosity of this wearing course can also be increased, thereby improving its water drainage capability. In order to achieve this, the number of holes is increased up to 20% by using thicker chippings and reducing the amounts of fine aggregates (or fines). The increased ability to drain water decreases the risks of sudden loss of tyre adhesion caused by excess water, also known as aquaplaning. Moreover, the amount of spray from the pavement onto vehicle windscreens is reduced, thus increasing driving safety. However, this type of texture makes the material more likely to break up and to age faster due to the higher accessibility of air to the inside.

The high technical performance required of long-lasting thin-layer wearing courses and porous wearing courses can be attained through the use of bitumen-modified binders.

Dynasol's styrene-butadiene copolymers assure safe, quiet, long lasting bitumen-modified binders, their performance in a wide range of temperatures prevents softening and cracking of the asphalt, and provides water resistant properties to the compound.

Our elastomers are made of styrene and butadiene monomers. Both compounds are polymerized to form selectively ordered styrene butadiene blocks. As the following Table A shows, Dynasol offers elastomers with different structures and compositions.

Solprene® and Calprene® by Dynasol

Solprene® SBR as S-1205 and S-1110 are widely used as asphalt modifiers for paving roads, owing to the ease with which it can be dissolved in liquid asphalt; S-1205 and S-1110 offer (-) significant advantages over other similar polymers in the market. When blended with asphalt and a cross-linking agent, the product creates a chemical structure in the asphalt, which increases the temperature service range (see rubber structure in Fig. 2).

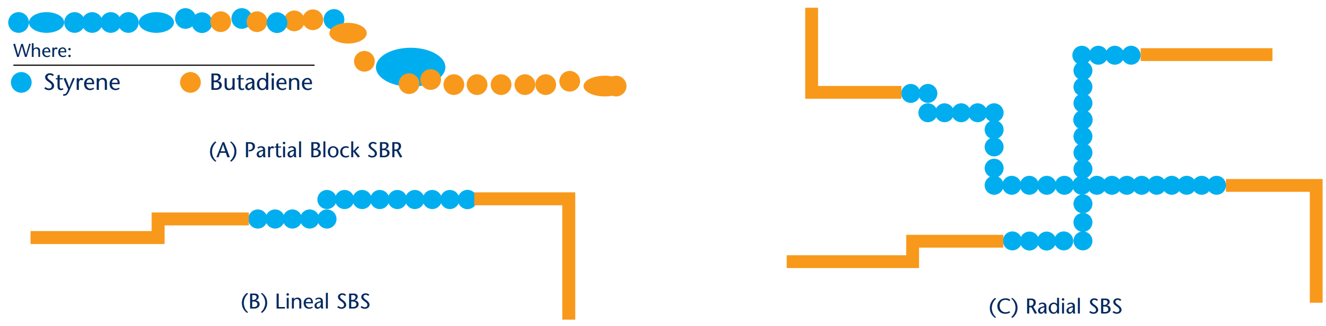
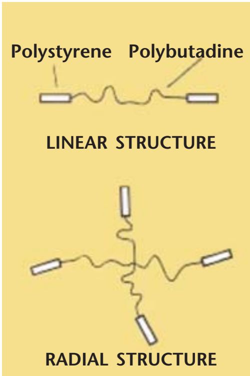


Figure 2. **Rubber Structures for Modified Asphalt**

Solprene® and Calprene® SBS provide the same properties, however a cross-linking agent is not required. (-) SBS thermoplastic rubbers are styrene and butadiene copolymers with teleblock configuration. The central chains of polybutadiene (of linear or tetra radial structure) have polystyrene blocks bonded to their ends. The molecular aggregates are the result of the association of different molecules by formation of polystyrene domains between them (Fig. 2 & 3).

These rigid polystyrene domains are the ones, which establish a three-dimensional network that gives SBS its self-reinforcing characteristics without the need for cross-linking agents. The central polybutadiene chains, however, are flexible and impart to the polymer its elastic properties and flexibility at low temperatures.

Above the glass transition temperature of polystyrene (Tg = 100 °C), the polystyrene domains soften, the molecules are freed, and the material flows. This process is reversible, so that when cooled the polystyrene domains are re-established.



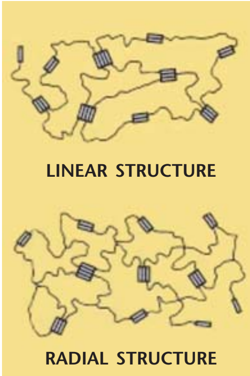


Figure 3.

The SBS thermoplastic rubbers morphologically consist of polystyrene domains of essentially spherical geometry (approximate diameter = 300 Angstrom) embedded in a polybutadiene matrix (Fig. 4).

When SBS thermoplastic rubbers are combined with bitumen in a suitable mixer, the polystyrene domains swell up through absorption of part of the resins and oils within the bitumen. The swollen rubber, under the combined action of heat and sheer forces produced by the mixer, is dispersed in the bitumen.

Table A

Solprene®

Type	S-1205	S-1110	S-411	S-416
Structure	Block Linear SBR	Block Linear SBR	Radial SBS	Radial SBS
% Styrene	25	30	30	30
Molecular weight	Low	Medium	High	Medium

Calprene®

Type	C-401	C-411	C-412	C-419
Structure	Radial SBS	Radial SBS	Radial SBS	Radial SBS
% Styrene	20	30	30	30
Molecular weight	Medium	High	High	Medium

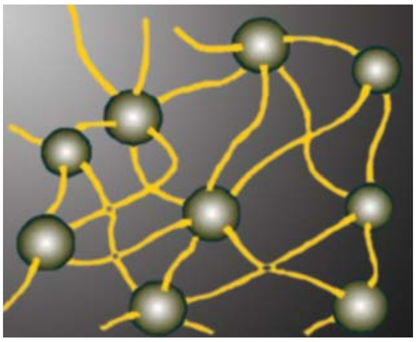


Figure 4. **SBS Morphology**

Benefits

Our elastomers provide countless benefits for asphalt used in road construction:

- Improvement of the fatigue resistance.
- Improvement of the resistance to deformation caused by heavy loads.
- Prevention of softening at high temperature.
- Improvement of the resistance to cracking caused by low temperature and/or abrupt changes in loads in high traffic zones.
- They allow safer, quieter and long-lasting highways.
- Reduction of rutting.
- Reduction of maintenance costs.

Polymer modified asphalt may be the best solution for correcting a large number of paving defects, but other factors must as be taken into account, such as the type of paving and hot mix.

S-4318
Linear SBS
33
Low

C-500	C-501
Linear SBS	Linear SBS
30	31
Low	Medium

Asphalt Composition

Certain asphalts are not compatible for rubber modification. The most cost effective way of determining this is to know its composition.

Being a complex mixture asphalt composition can vary considerably depending on where the ingredients come from. Asphalt components are generally classified into two groups: Asphaltenes and Maltenes.

The asphaltene groups consist of polynuclear hydrocarbons of a molecular weight up to 20,000, and which are insoluble in n-heptane. On the other hand, petrolenes or maltenes are soluble in n-heptane and are categorized as resins, aromatics and saturates. Resins are both solid and amorphous bodies, while aromatics are low molecular weight paraffin and naphtene -based oils.

Rubber modifiable asphalts are those that are low in asphaltenes yet have enough oils to dissolve the polymer. Polymer dissolution is the basis for modifying asphalt properties. As such the compatibility between the synthetic rubber and asphalt is a key factor in efficient modification.

Compatibility is determined by two factors:

- Asphalt composition.
- The polymer’s molecular structure.

Asphalt factor

As can be seen in the table below, asphalt components demonstrate different polar characteristics. Non-polar solvents primarily dissolve SBS thermoplastics elastomers (both radial and linear) and saturated polymers. Naphtenes aromatics also have this ability, but to a lesser degree. Both of these groups are Maltenes.

The chemical composition of the asphalt is therefore what determines its compatibility with the polymer, and its dissolution capability depends on the aromatic saturates contained in the maltene phase.

Component	Polarity
Asphalthenes	Very high
Polar aromatics	High
Naphtenes aromatics	Low
Saturates	None

The higher this percentage, the greater the ability of the polymer to dissolve.

Certain research shows that viscosity is another factor that should be considered, since compatibility between asphalt and rubber decreases when asphalt has a higher degree of viscosity.

Polymer factor

Radial styrene butadiene rubber (SBS) is made up of two different blocks: a hard styrene thermoplastics polymer and a soft butadiene elastomer, the polybutadiene block absorbs oil and expands. This causes long polymer chains to unravel, setting in motion a mechanism whereby the polymer is dissolved in the asphalt.

This dissolution mechanism is a continuous process that is divided into three stages:

- Stage one: the polymer is completely coiled.
- Stage two: the polymer begins to unfold as its polybutadiene block reacts to the solvent in the asphalt.
- Stage three: the polymer dissolves completely. Once this occurs, the asphalt compound, which caused the polybutadiene block to swell, may only be extracted through a special process this means that the dissolution process is irreversible under normal industrial conditions.

Once the polymer is dissolved in the asphalt its chains lose mobility, thus increasing the viscosity on the asphalt. If the polymer does not dissolve after the final two stages, it remains encapsulated with its original density and enough mobility to cause ingredients separation. After the polymer reaches its dissolution point, a new point of equilibrium is observed in which the separation of the encapsulated polymer can no longer occur. However the extended polymer chains and differences in density still make separation a limited possibility.

Linear SBS dissolves easily in asphalt in comparison to radial SBS for geometrical reasons, not with standing, the network they form is less effective for modifying asphalt than radial compound.

Methods for Measuring Dispersion

Dissolution is one the processes that determine the quality of the asphalt. When an appropriate level of homogenization is reached, as well as an adequate formation of the rubber network, it can be said that the dissolution process is complete.

As can be seen in the following table there are different methods for evaluating the quality of this process.

Direct methods	Indirect methods
Assure that a thin surface film has developed on the asphalt, and that no use dissolved polymer fragment one visible to the eyes. Pour the liquid asphalt on a piece of silicon paper and wait until dry. Once dried, hold the paper at both ends and stretch it under a lamp to check for possible imperfections on the film.	The most effective method is to evaluate the asphalt performance parameters and compare them against the desire results. This method require highly reliable lists to establish the following: ● Flow point. ● Break point. ● Viscosity or rheometry.
Another direct method is to observe the asphalt with a fluorescent microscope such as a Zeiss Axiolab A, with a 200x, 500x, and 1000x, ICB optical system.	Establishing two of these parameters is sufficient for assuring a proper quality control.

Mixing Methods

Asphalt companies and laboratories use different types of equipment to incorporate the polymer into a mix. Conventional paddle or spiral hot mix systems are among the most frequently used. However, this equipment may require longer mixing time for certain operations or when specific types of asphalt and polymers are being employed.

Mixing times can be reduced by replacing conventional mixer for high sheer power systems. Rotary systems, such as the Siefer, Nardini and other similar ones are the most commonly used for high viscosity formulations with large amounts of polymers and mineral fillers.

Certain points should to be taken into account when using different types of mixers:

- Low sheer mixers require a smaller investment and consume less energy.
- High speed, high sheer mixers allow a reduction from hours to minutes in the time needed for polymer dissolution, regardless of the material's physical form.
- A high-powered mixer reduces both mixing time and the risk of significant polymer decomposition.
- While mixing temperatures normally vary between 180-190 °C, mixing times –which range from 30 minutes to 2 hours– depend on the mixer it self, rubber concentrations, and type of asphalt.

Storage

Optimum storage of modified asphalt requires the following conditions to be observed:

- Although additives such as nitrogen and antioxidants are expensive, they significantly reduce the risk of asphalt decomposition especially under severe conditions.
- Normal storage tanks may fluctuate between 157 and 163 °C; thermal insulation is the ideal medium for controlling the temperature of heating systems.
- Mixing should be maintained whenever possible by using a mechanical systems and/or re-circulation pumps.
- The storage temperature should never exceed 200°C, nor should it remains above 193°C, for longer than two hours.
- During prolonged storage periods (several days) the material should only be allowed to cool to a minimum temperature of 135°C, in tanks with high grade mechanical mixing systems, or 149°C when tanks with less good mixing systems or re-circulation pumps are used. Stored asphalt must be recirculated once a day and reheated at least for 24 hours before being used.

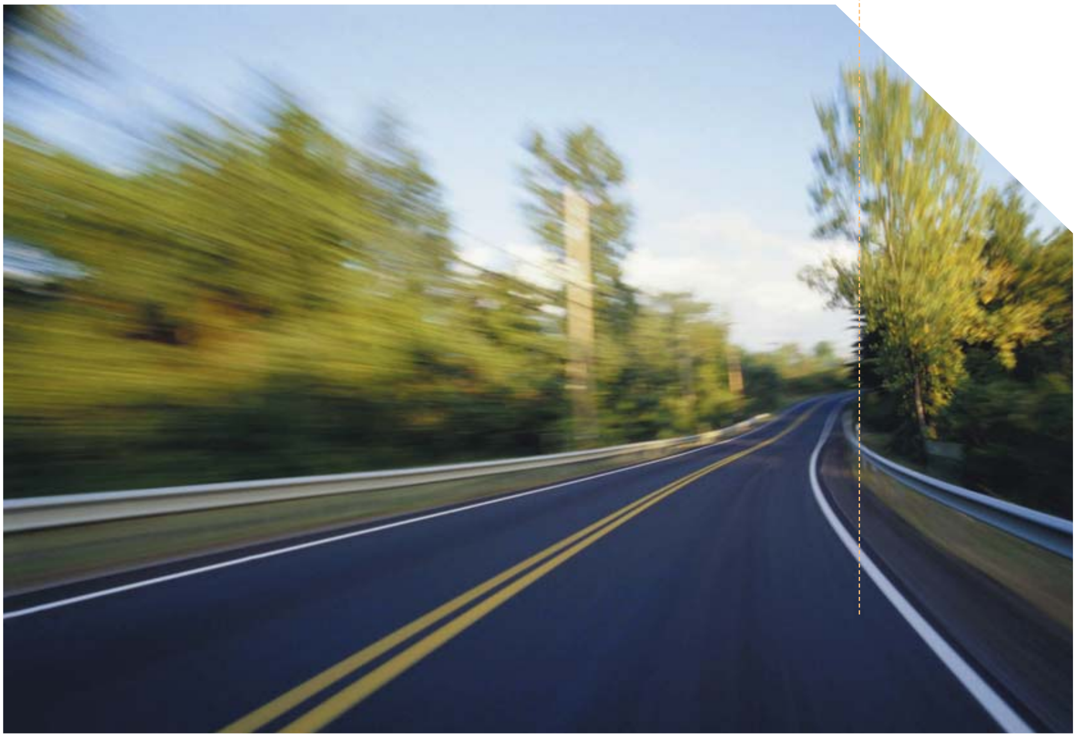
In order to avoid hot spots during the heating stage, care should be taken to ensure that there is an even mix. The ideal storage condition would be to have a specially designed tank for modified tank.

Polymer Degradation

Due to its chemical nature polybutadiene is proving to thermal mechanical breakdown. This fact must be taken into consideration when storing SBS modified asphalt.

Factors, which increase the tendency towards degradation, are:

- Temperature.
- Mechanical stress: higher sheer forces increase decomposition levels.
- Oxygen concentration: since oxygen is a mixing agent, high concentrations result in quicker decomposition.
- Crossling agents: sulfur is a vulcanizing agent and will contribute to the thickening of the mix.



Measuring the Performance of Modified Asphalt

Properties of bitumen/rubber mixtures

Basic laboratory tests:

- ***Penetration test***. This test is carried out by placing a needle on the surface of the asphalt, which is maintained at a constant temperature. Penetration is measured by the length that the needle descends in a given time.
- ***Softening point (ring & ball)***. Here liquid asphalt is poured into a small ring mold and left to solidify. Subsequently, a small metal ball is placed on the asphalt and the temperature of the material gradually increased. The temperature at which the ball passes through the ring indicates the softening point of the asphalt.
- ***Cold flexibility***. It is the temperature at which a sample breaks due to low temperature. It is measured by means of a Frass instrument.
- ***Ductility***. The ability of a material to withstand large inelastic deformations without fracture. For asphalt binders, ductility is measured as the length in centimeters that the sample reaches before total separation.
- ***Elastic recovery***. It measures the ability of a material to recover its original size after deformation. The result shows the percentage of the original size and shape regained.

Tables B and C depict the properties of Calprene and Solprene mixtures with a compatible bitumen of two different types. As we can see, rubbers, even in concentrations as low as 2%, have a clear modifying effect upon the bitumen. This effect is apparent through an increase in the softening temperature and viscosity, as well as a decrease in penetration and brittleness temperature. Moreover, a gradual increase in the amount of rubber (of any type) will increase the modifying effect. There is also a clear influence of the rubber type on the softening temperature, with molecular weight and styrene contents exerting the greatest influences. In compounds with 4 and 6% rubber concentrations, Calprene 401, with its lower styrene content (20%), is the one which least increases the ring & ball temperature. For polymers with a higher styrene content (30%), the softening temperatures rise as the molecular weight of the rubbers increase.

Repsol 80/100 Bitume

Repsol 80/100, %
Calprene 401, %
Solprene 416, %
Calprene 501, %
Calprene 419, %
Penetration at 25 °C, 1/10 mm
Ring & Ball, °C
Viscosity at 160 °C, cps
Viscosity at 180 °C, cps
Cold flexibility, Frass °C
Ductility at 5 °C, mm
Elastic recovery at 5 °C, %

Mexican AC-20 Asphalt Modifi

Sample	F-1
AC-20 virgin Mexican asphalt (PG=64-22)	100
Solprene 411	
Solprene 416	
Solprene 1205	
Solprene 1110	
Solprene 4318	
Penetration at 25 °C, 1/10 mm	65
Ring & Ball, °C	41
Viscosity at 160 °C, cps	365
Viscosity at 180 °C, cps	203
Cold flexibility, Frass °C	-13
Elastic recovery at 5 °C, %	Not avail.

Table B

n Modified with Calprene 401, Solprene 416, Calprene 501 and Calprene 419

100	98	96	94	98	96	94	98	96	94	98	96	94
	2	4	6									
				2	4	6						
							2	4	6			
										2	4	6
85	70	55	50	65	53	47	69	60	48	65	54	47
38	49	66	73	48	70	86	49	75	90	50	86	99
190	279	418	1068	209	400	613	223	419	919	251	446	836
75	112	251	362	111	181	320	111	251	390	139	237	464
-15	-17	-20	-26	-18	-18	-28	-17	-18	-22	-17	-19	-22
20	140	320	350	133	280	350	140	300	650	140	250	365
-	-	70	80	-	70	75	-	65	70	-	70	73

Table C

ed with Solprene 411, Solprene 416, Solprene 1205, Solprene 1110 and Solprene 4318

F-2	F-3	F-4	F-5	F-6	F-7	F-8	F-9	F-10	F-11	F-12	F-13	F-14	F-15	F-16
2	4	6												
			2	4	6									
						2	4	6						
									2	4	6			
												2	4	6
54	46	41	57	51	48	58	48	43	51	49	47	60	58	52
62	80	97	59	67	87	60	64	69	58	63	73	56	65	84
481	793	2098	413	621	1785	397	615	843	477	766	2345	372	488	711
217	225	625	213	221	510	218	237	477	213	221	638	210	219	413
-17	-19	-24	-19	-21	-27	-16	-19	-25	-14	-21	-23	-17	-21	-26
Not avail.	67	71	Not avail.	71	75	Not avail.	72	81	Not avail.	73	84	Not avail.	69	74

The following figures show the properties evolution as Solprene/Calprene rubber modify a compatible asphalt

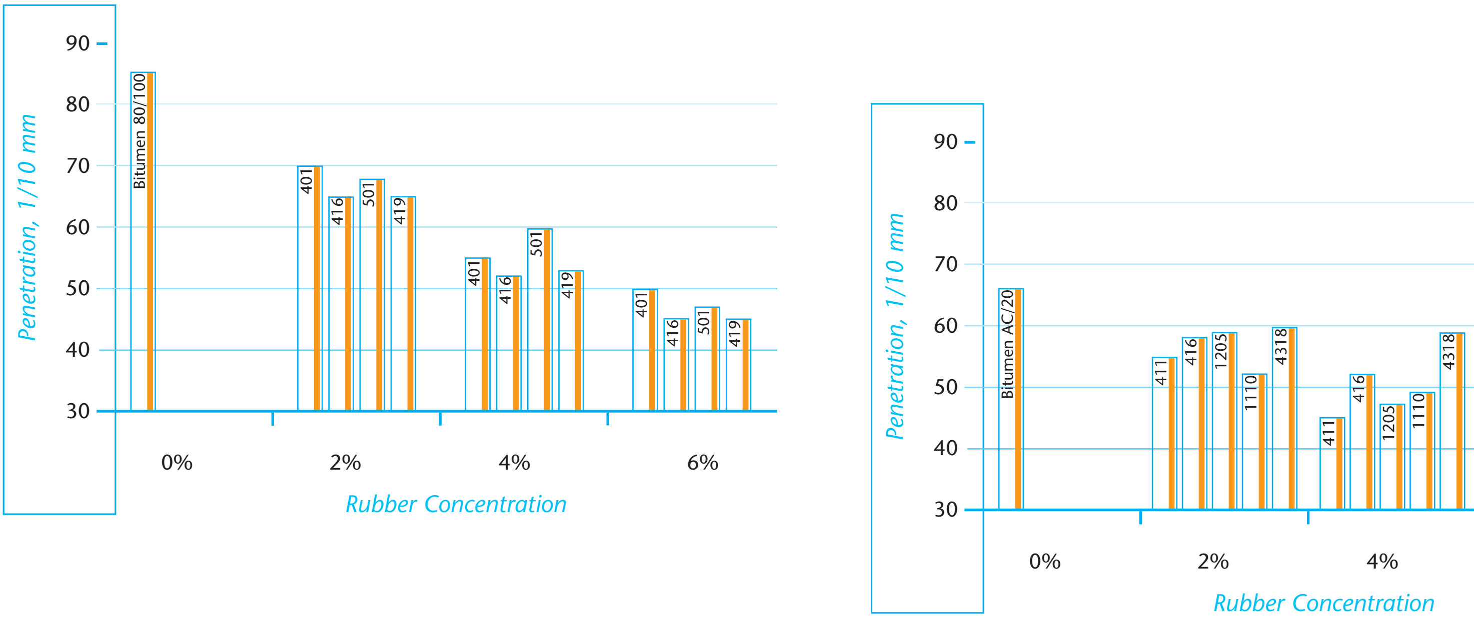


Figure 5. **Penetration vs Rubber Concentration**

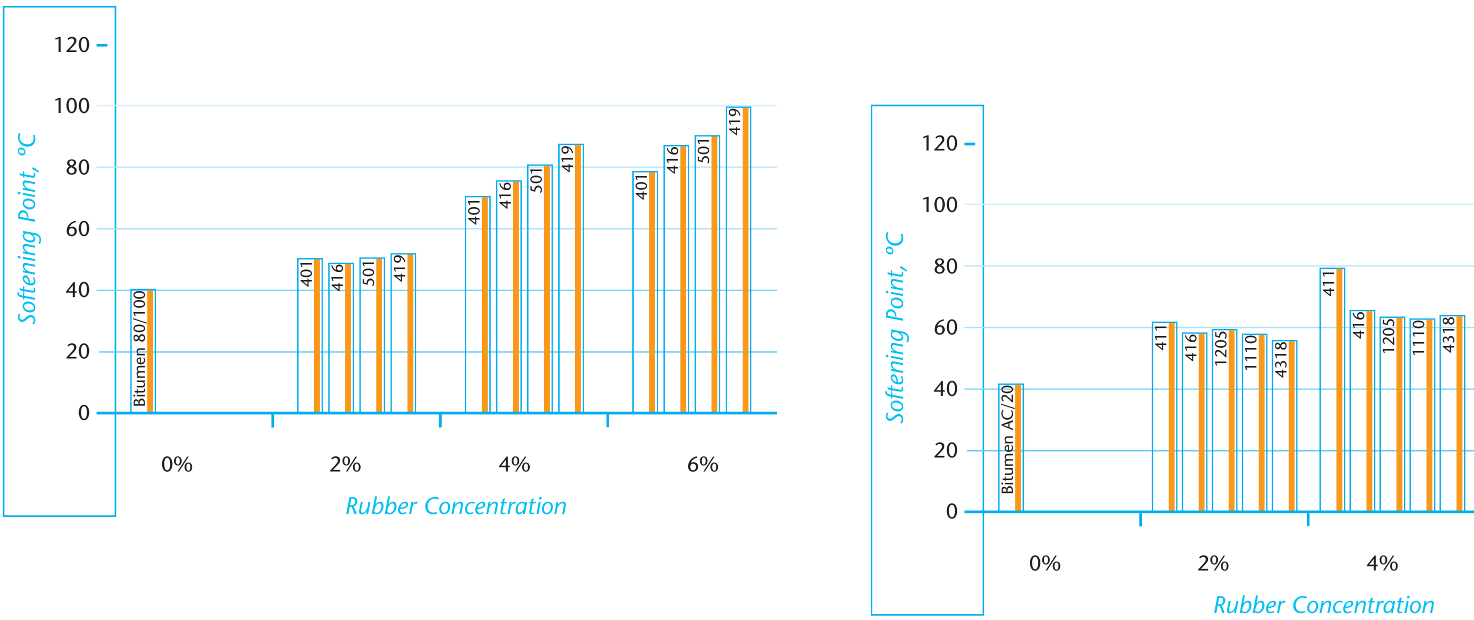
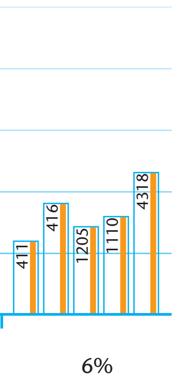
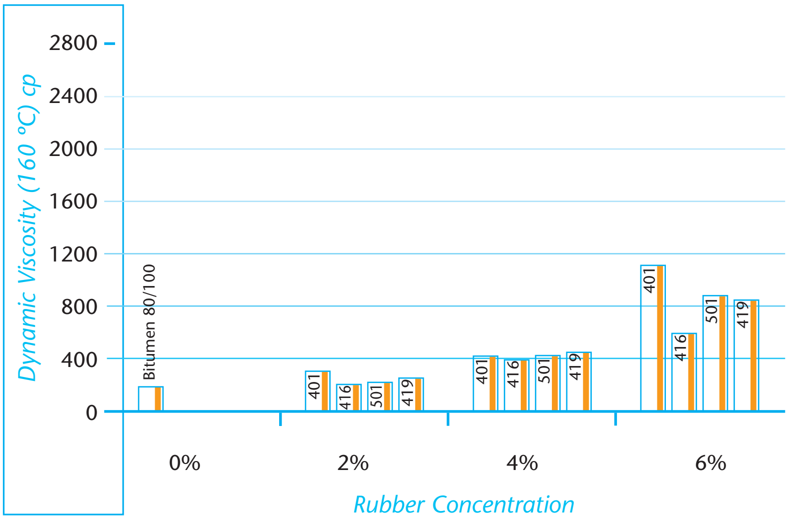
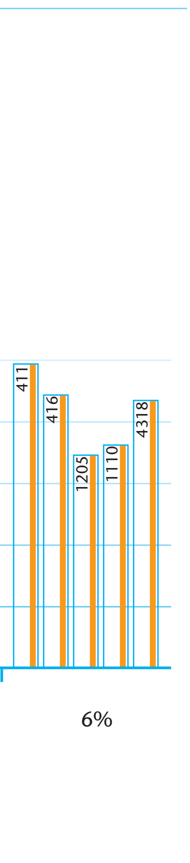


Figure 6. **Softening Point vs Rubber Concentration**







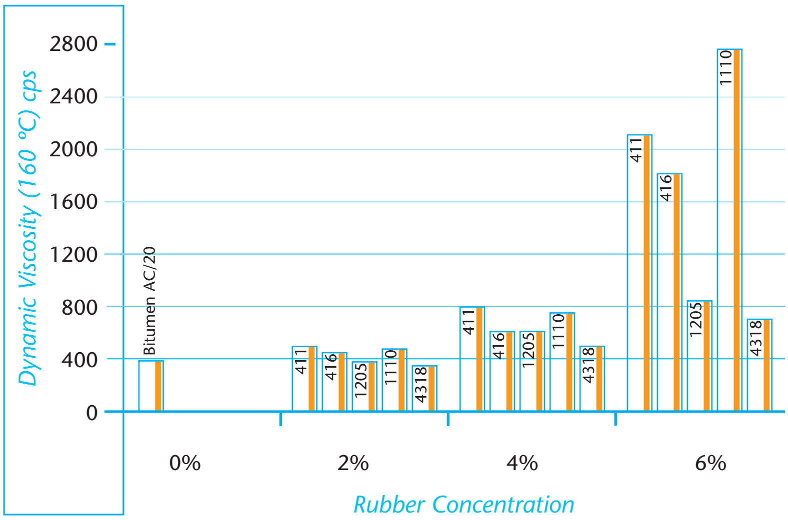


Figure 7. **Dynamic Viscosity (160 °C) vs Rubber Concentration**

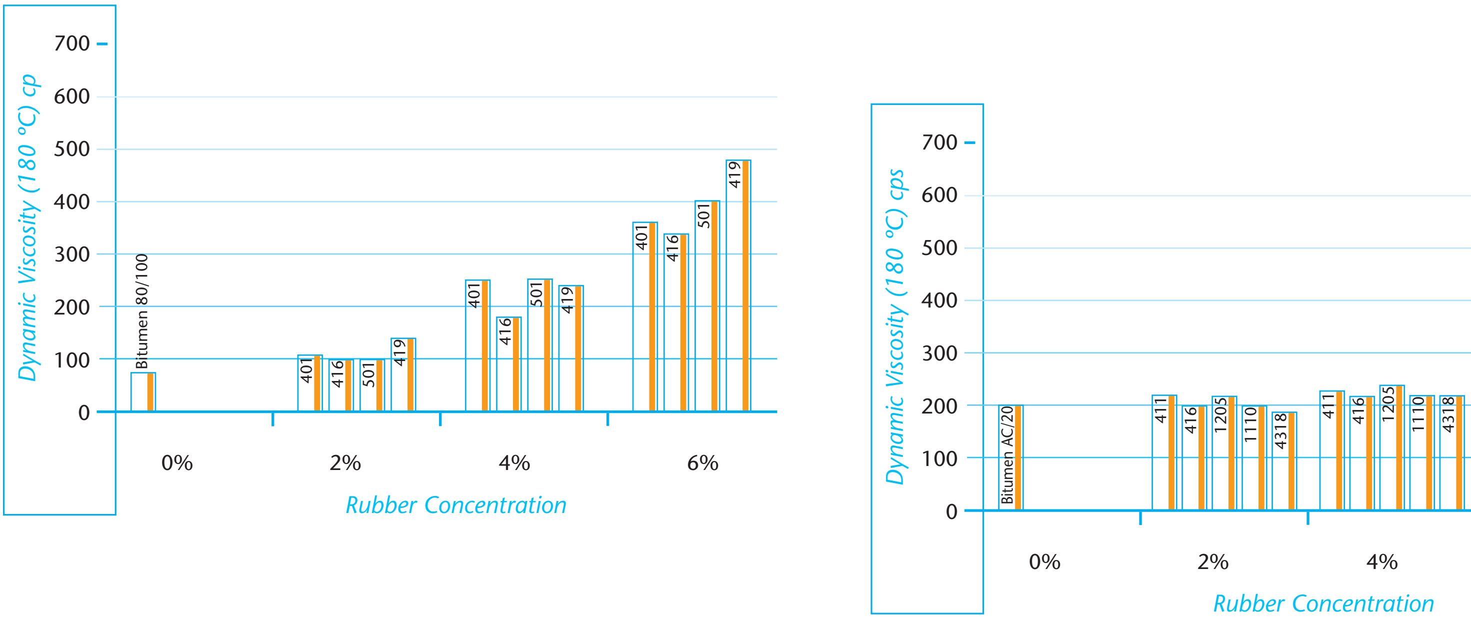


Figure 8. **Dynamic Viscosity (180°) vs Rubber Concentration**

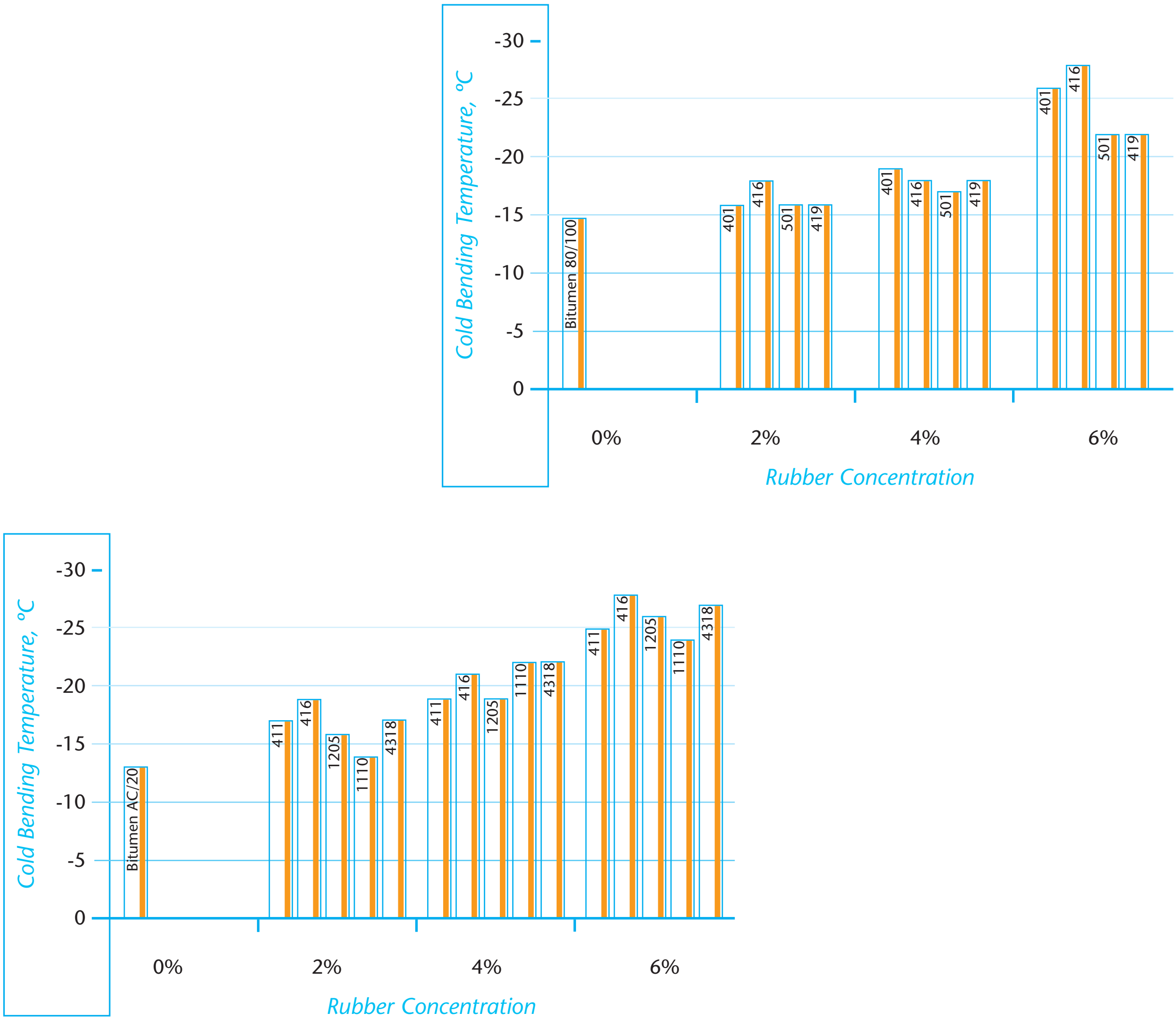
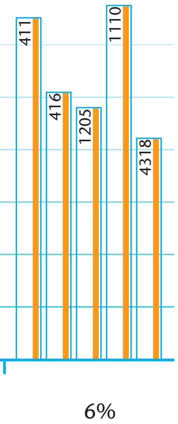


Figure 9. **Cold Bending Temperature vs Rubber Concentration**



SHRP Grade

SHRP (Strategic Highways Research Program) Specifications have been developed in the U.S.A. to control the influence of a binder on permanent deformation at high temperatures, brittleness at low temperatures and fatigue resistance at low and medium temperatures, in a pavement after a certain period of continuous service.

The various grades of binders are named as PG (Performance Grade) followed by two numbers, which indicate maximum and minimum service temperatures (°C) for which a binder yields adequate results. The temperatures are those that the pavement may reach and are calculated from the air temperature of the environment.

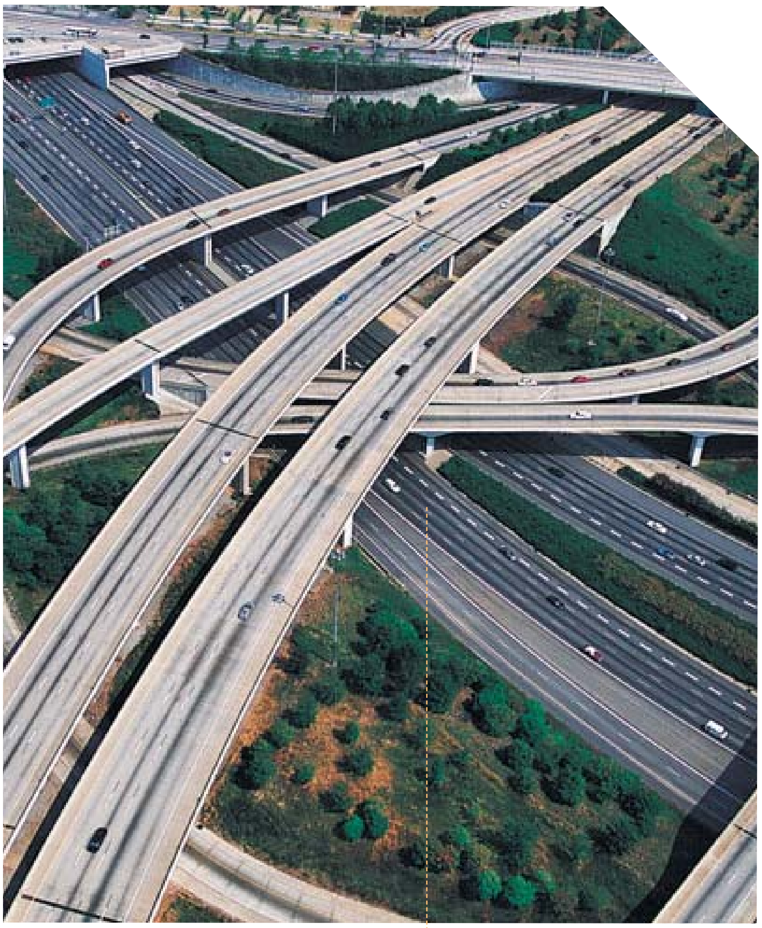
Permanent deformation and fatigue resistance are evaluated through dynamic tests using a dynamic sheer rheometer (DSR), which are measured using the following parameters:

- G’ = Dynamic storage modulus (elastic component)
- G” = Dynamic loss modulus (viscous component)
- G* = Complex modulus
- δ = Phase angle

The value G*/sin δ is related to permanent deformation. It states the reciprocal value of the binder, viscous flowage or the tendency to permanent deformation. The values of this term should reach a minimum of 1 KPa for the fresh binder and 2,2 KPa after RTFOT (Rolling Thin Film Oven Test) aging.

The value G*•sin δ relates to fatigue resistance. It accounts for loss modulus or viscous modulus. The test is carried out with a sample, already RTFOT aged, which has been submitted to long term PAV (Pressure Ageing Vessel) ageing. It is specified that G*•sin δ value should be less than 5000 KPa.

As far as brittleness at low temperature is concerned, this is determined through a Bending Beam Rheometer (BBR). On a prismatic beam of asphalt binder a load is applied to measure the stiffness-modulus. As the temperature decreases the stiffness of the material increases. The key question is whether cracking arises as a result of the binder exceeding a critical limiting stiffness-modulus at a limiting stiffening temperature. To avoid fracture at low temperatures, it is specified that the stiffness modulus should be below 300 MPa.



Bitumen
B40/50
B60/70
B150/200
Bitumen modified with 4 % C -501

(1) G*/sen δ > 1.0 KPa*
(2) G*/sen δ > 2.2 KPa*
(3) G*.sen δ < 5.0 MPa
(4) S < 300 MPa**
(5) m > 0.3**

The binder based on Calprene 501 (see Table D) fully satisfies all requirements of SHRP Specifications. It corresponds to a PG 70-22 Grade, thereby qualifying it for use within temperature limits ranging from 70 ºC to -22 ºC.

Table D

G*/sin δ (Kpa		G*.sin δ (MPa)(3)	S (MPa)(4)	m(5)	Grade
Fresco(1)	RTFOT(2)				
1.45 @64ºC	16.5 @ 64ºC	3.95 @25ºC	82 @-6ºC	0.33 @-6ºC	PG 70-16
1.63 @64ºC	7.89 @ 64ºC	1.32 @22ºC	81 @-6ºC	0.35 @-6ºC	PG 64-16
1.01 @76ºC	5.98 @ 58ºC	4.66 @13ºC	130 @-18ºC	0.31@-18ºC	PG 50-28
2.15 @76ºC	2.61 @ 70ºC	4.29 @19ºC	149 @-12ºC	0.36@-12ºC	PG 70-22

Table E. Rheological parameters of Mexican AC-10 and AC-20 asphalt (unmodified)

Mexican AC-10 asphalt

Temperature, °C	Strain, kPa	Stress, kPa	Phase angle	G* Sheer modulus, kPa	G*/SIN delta, kPa	SHRP result
52	0.0299	0.151	82.2	5.051	5.098	Pass
58	0.0677	0.151	84.2	2.228	2.239	Pass
64	0.1435	0.149	85.9	1.037	1.04	Pass
70	0.2866	0.148	87.3	0.515	0.515	Not pass
76	0.5512	0.147	88.4	0.268	0.268	Not pass

Mexican AC-20 asphalt

Temperature, °C	Strain, kPa	Stress, kPa	Phase angle	G* Sheer modulus, kPa	G*/SIN delta, kPa	SHRP result
52	0.0193	0.151	80.3	7.806	7.92	Pass
58	0.0876	0.151	82.6	3.331	3.358	Pass
64	0.0973	0.151	84.6	1.547	1.554	Pass
70	0.1999	0.148	86.3	0.731	0.733	Not pass
76	0.3912	0.146	87.7	0.377	0.378	Not pass

Tables E, F and G show how rubber modification allows to obtain better performance in SHRP grades, however as we mention in the beginning table F shows a clear effect from asphalt nature to get better performance. In this case AC-20 is heavier asphalt in comparison with AC-10. This characteristic permits to increment the performance SHRP grade of 76 using Solprene 411.

Asphalt source is another important variable to consider during asphalt modification. Table E shows rheological parameters according with SHRP regulations of two virgin asphalts from Mexico AC-10 and AC-20 grades.

Table F. Modified asphalt using Solprene 411

Solprene 411 at 3% weight in asphalt AC-10

Temperature, °C	Strain, kPa	Stress, kPa	Phase angle	G* Sheer modulus, kPa	G*/SIN delta, kPa	SHRP result
52	0.0184	0.153	72.1	8.205	8.622	Pass
58	0.0373	0.152	73.7	4.079	4.249	Pass
64	0.0734	0.152	75.9	2.085	2.151	Pass
70	0.1393	0.151	78.2	1.101	1.124	Pass
76	0.2474	0.149	80.7	0.601	0.609	Not pass

Solprene 411 at 3% weight in asphalt AC-20

Temperature, °C	Strain, kPa	Stress, kPa	Phase angle	G* Sheer modulus, kPa	G*/SIN delta, kPa	SHRP result
52	0.0096	0.153	70.6	15.701	16.649	Pass
58	0.0196	0.153	72.3	7.712	8.097	Pass
64	0.04	0.152	74.5	3.801	3.944	Pass
70	0.078	0.152	77.1	1.961	2.012	Pass
76	0.1458	0.151	79.6	1.046	1.063	Pass

Table G. Modified asphalt using Solprene 1205

Solprene 1205 at 3% weight in asphalt AC-10

Temperature, °C	Strain, kPa	Stress, kPa	Phase angle	G* Sheer modulus, kPa	G*/SIN delta, kPa	SHRP result
52	0.014	0.153	73.7	10.753	11.203	Pass
58	0.0302	0.152	75.5	5.017	5.181	Pass
64	0.0613	0.152	77.2	2.489	2.553	Pass
70	0.1187	0.151	78.8	1.288	1.313	Pass
76	0.2145	0.15	80.9	0.699	0.708	Not pass

Solprene 1205 at 3% weight in asphalt AC-20

Temperature, °C	Strain, kPa	Stress, kPa	Phase angle	G* Sheer modulus, kPa	G*/SIN delta, kPa	SHRP result
52	0.089	0.152	73	16.855	17.625	Pass
58	0.0195	0.152	75.1	7.759	8.027	Pass
64	0.0407	0.152	77	3.728	3.825	Pass
70	0.0816	0.151	78.8	1.868	1.904	Pass
76	0.1548	0.151	80.8	0.98	0.993	Not pass

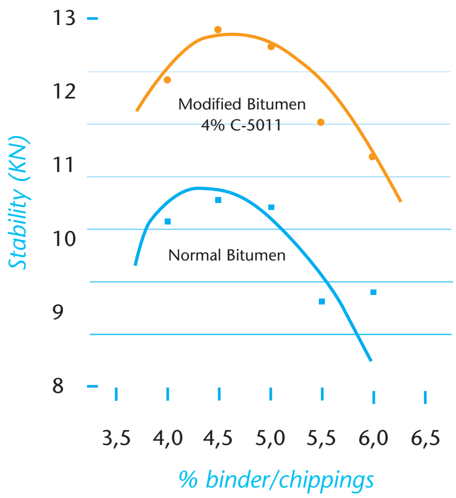


Figure 10. **Marshall Test**

Other properties

The following properties were determined on a binder made of Calprene 501 and compatible bitumen of 80/100 penetration. Calprene 501 concentration in bitumen was 4 % in all cases.

Marshall Test

The first step is to manufacture cylindrical specimens (10 cm in diameter x 6,35 cm high) from a chippings/binder aggregate through a compaction hammer in a cylindrical mould.
Subsequently, the test specimens are pressed between the two special cylindrical jaws of a Dynamometer, until they crush. The maximum load the testing sample will carry before failure and the amount of deformation of the specimen before failure occurred are known as "Marshall Stability" and "Marshall Flow", respectively.

Rutting Resistance

The wheel-tracking test is used to evaluate the resistance of a bituminous mix to plastic deformation. By this method the rutting resistance of a pavement under simulated severe traffic conditions is measured.
The test is done by repeatedly rolling a rubber-coated wheel on the asphalt sample. The sample is placed in a water bath at 40 °C and a load of 21kgs is applied to the wheels.
The performance of the material is assessed by measuring the resultant rut depth (mm) after a given number of passes (cycles).

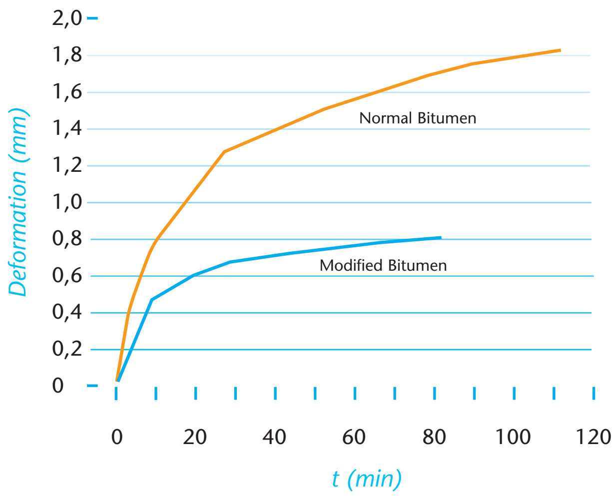


Figure 11. **Rutting/Resistance**

Handling and Storage

Dynasol's products are packed for normal handling conditions. Recommended storage conditions are: ventilated areas protected from humidity and the sun.

Quality

All Dynasol's activities are certified according to ISO 9001:2000 standards.

Technical Data Sheets and MSDS are available upon request.

Environmental Management System (EMS)

Both Santander and Altamira production sites are certified according to ISO 14001:1996 standards.

Technical Service and Development

Our Technical Service and Development Centre has the capability and capacity to give a qualified solution to our customers' needs.

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