HIGH PERFORMANCES ASPHALT MATERIALS FOR SUSTAINABLE PAVEMENT

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1 INTRODUCTION

The rapid development of the world economy and especially in ASIA region during the last two decades has generated a strong growth of heavy traffic on main road networks and by consequence requires a high level of maintenance of existing roads or new road building. This heavy traffic constituted of single, double or even triple wheel axles trucks influence the durability and the long term performances of pavement making roads structure more vulnerable to deformation.

The direct consequences of this increasing aggressiveness result in deep and fast structural deterioration of road structures that are characterized by two main distress modes: the permanent deformation (also called rutting) and cracking by fatigue.

Causes are well-known:

- Pavement design method: Lack of reliable data of traffic and axle load in addition with inappropriate design methodology can result in underestimated thickness of asphalt layers.
- Outdated asphalt pavement specifications: So far they are based on volumetric method (Marshall) and not on mechanical performances (Stiffness Modulus, resistance to rutting and to fatigue)
- Inappropriate bitumen choice: In many countries, the common practice still consists in using soft grade pure bitumen which is inappropriate to withstand severe constrains of traffic and high service temperature.

Performances of binder play a key role in the performances of the asphalt pavement as the properties of both are linked. Using Polymer Modified Bitumen can improve considerably the pavement performances for wearing course and binder course regarding the Rutting resistance and thermal susceptibility.

Using in pavement structure base course Asphalt Concrete manufactured with Hard Grade bitumen like “High Modulus Asphalt” or French “Enrobé à Module Elevé” with improved mechanical characteristics can lead to pavement reduction thickness or longer service life, by preserving resources and bringing cost savings.

Combination of this both type of “High Performances Asphalt”, PMB for surface course and Hard Grade for base course, with the strong extension of service life and increase of traffic being supported, make these specific materials economical by reducing significantly the frequency of maintenance and the thickness of asphalt layers.

This paper focusses on the presentation of characteristics and performances of asphalt materials using specific type of bitumen and their impact on asphalt pavements durability illustrated by some case studies.

2 KEY PARAMETERS FOR SUSTAINABLE PAVEMENTS

Solutions are numerous and clearly identified but the key parameters to consider are the following:

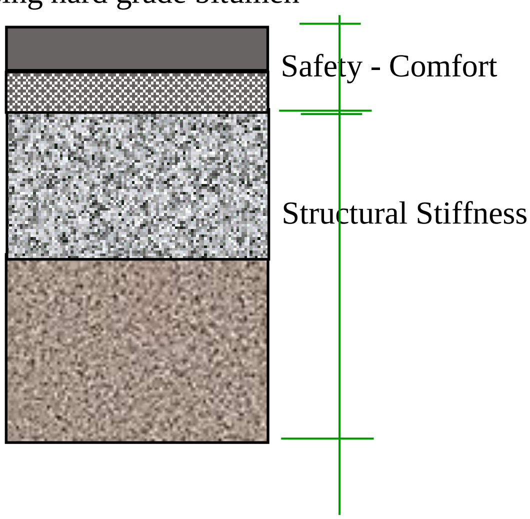
2.1 Adequate Pavement design Method:

Using an analytical methods such as ALIZE from the LCPC (French road authorities) for example will provide tailored solution for any type of traffic and axle load taking into consideration reliable data such as the heavy traffic per day, the real axle load, the excepted service life of the pavement but also taking into account the real performances (deformability, stiffness modulus) of layers at local weather conditions.
This method is adapted to extreme situation such as heavy duty roads, industrial platform, mine tracks and static loads.

Axle Load and traffic: These data must be fully reliable and this is a mean issue in some parts of the world. Some Asian countries have now installed weighting and counting stations on their main roads network in order to update the knowledge of their traffic and axle load. Of course reliability involve permanent updating as the profile of traffic follows the industrial development

Another fundamental concept in pavement design consists in separating the functions of asphalt layers as follows

- Wearing course: Mostly thin overlay which does not account in the calculation of the structure meant to improve the safety and comfort of road users. The main focuses are the Skid resistance – Superficial drainage and Evenness
- Bounding and waterproofing the base course with tack coat emulsion
- Base course: Structural focus based on high stiffness modulus asphalt pavement for re-enforcing the bearing capacity of the structure, extending the service life and reducing the frequency of maintenance using hard grade bitumen



2.2 Performances based specifications of Asphalt Concrete

Up to now specifications of Hot Mixes in most of the countries worldwide are still based on the Marshall Method and empirical recipes. Even if this approach has demonstrated its suitability until a recent past it find its own limits especially in cases of ultimate conditions of traffic

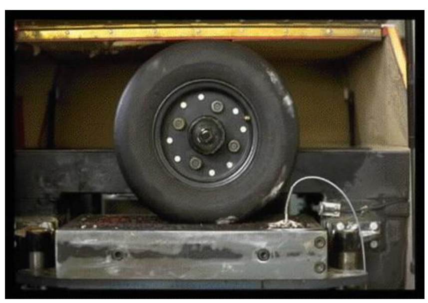
In order to meet highest requirement asphalt pavement layers must

- Resist to rutting at high service temperature under high axle load (Bitumen stiffness)
- Resist to fatigue cracking (use of PMB)
- Be workable for easy laying and compaction
- Be waterproof for preserving underneath structure
- Be sustainable and resist to the abrasion and effects of water
- Be cost effective

Meeting the above requirements imply to re-consider the method of designing and providing predictive testing methods based on performances specifications. In Europe, the formulation method for asphalt mixes used is defined by standards. It is characterized by an approach based as much as possible on the performances of the mixture. For materials that play a structural role, it can be classified in the "fundamental" approach. Asphalt Concrete follows the requirements of the following European standards:
-NF EN 13108-1 concerning the specifications for asphalt mixes
- NF EN 13108-20 concerning the formulation method

The mix design method requires specifications on the components and particularly the aggregate but it involves 5 tests which define the level of the study to perform on the asphalt mix:

- The Gyrator Compaction test and the water resistance test -> level 1
- Resistance to rutting -> level 2
- The stiffness modulus -> level 3
- Resistance to fatigue -> level 4



The Gyratory Compaction Test – EN 12697-31 The rutting test – EN 12697-22

3 HIGH MODULUS ASPHALT FOR BASE COURSE

The worldwide trend tends to substitute soft binders by harder grades more adapted to stringent and severe conditions. Bitumen grades can be specified by their penetration, viscosity or Performance Grade. Most of local specifications now have extended their range to harder grades up to 20/30 or 40/50 (penetration grade) or higher Performance Grade (like PG 70-22 in the USA) and even 10/20 or 20/30 in Europe.

3.1 Binder characteristic for High Modulus Asphalt

Use of harder penetration bitumen grade to strengthen the asphalt layers and thus reducing the risk of rutting is now the trend. It applies to all asphalt layers. Authorities have gradually switched from 80/100 pen bitumen to 35/50 within 25 years. This grade represents now about 70% of asphalt pavement to date in France on national roads.

Harder grades (10/20-20/30) are now commonly used for base course in specific situations such as roundabouts, heavy trafficked lanes, trucks parking, toll gate and industrial platform where standards grades of bitumen can't withstand such high stresses and especially to design High Modulus Asphalt, called "Enrobé à Module Elevé" in France (EME).

3.2 Mix design for High Modulus Asphalt "EME"

The formulation of "Enrobé à Module Elevé" EME is closed to traditional Road Bituminous Base Asphalt. The aggregate mix is usually continuous graded with approximately 60-65% chippings and the filler content stands around 7%. The current chipping sizes are 10, 14 or 20mm but the most commonly one is 14mm.

Characteristics of aggregates such as angularity, cleanliness of crushed sand and chippings conforms to the standard for Road Base Asphalt

Designing EME consists to conciliate apparent contradictory performances that are:

- High Complex Modulus
- Good rutting resistance
- High fatigue resistance

The binder generally used is currently hard grade bitumen. Softer penetration grade bitumen can be used but they need to be hardened with additives or natural asphalt otherwise the stiffness modulus will never be reached. This process of modification can be useful in areas where hard grades are not available.

The good behavior in fatigue is ensured by a low void content (currently < 6%) and high dosage in bitumen forming a thick film of bitumen on the aggregates that provides a good deformability favorable to the auto-reparation
Designing Hot Mix Asphalt according to the European standardization is based on mechanical performances. Freedom is given to select the appropriate aggregate mix, bitumen grade, source and dosage to achieve the following requirements given in the table below.

Comparative performances GB (Road Bituminous Base Asphalt) vs EME according to the NF EN 13108-1

		GB			EME	
		GB2	GB3	GB4	EME1	EME2
Water resistance Duriez ratio r/R		> 0.65	> 0.70	> 0.70	> 0.70	> 0.75
Rutting Test @ 60oC						
- 8 to 11% void after 10,000 cycles	%	< 10				
- 7 to 10% void after 10,000 cycles	%		< 10			
- 5 to 8% void after 10,000 cycles	%			< 10		
- 7 to 10% void after 30,000 cycles	%				< 7.5%	
- 3 to 6% void after 30,000 cycles	%					< 7.5%
Complex Modulus at 15oC/10Hz						
- 7 to 10% void	Mpa	> 9,000	> 9,000		> 14,000	
- 5 to 8% void	MPa			> 11,000		
- 3 to 6% void	MPa					> 14,000
Fatigue Test at 10oC/25Hz, εε						
- 7 to 10% void	udef	> 80	> 90		> 100	
- 5 to 8% void	udef			> 100		
- 3 to 6% void	udef					> 130

We observe a continuity of performances from the GB2 to the EME 2 to answer the diversity of situations.

Dosage of bitumen in GB is conventional and use semi hard bitumen (35-50 penetration grade). This explains the air void content and the maximum elongation in fatigue (from 80 to 100 micro deformations).

Despite that none bitumen characteristic is required in the standard recommended penetration grades for designing EME are 20/30 – 15/25 and 10/20. They all conform to the European standard NF EN 12591

The main difference between the EME1 and EME2 results in the bitumen content. The EME1 is rather a premium GB4 based on equivalent bitumen dosage while the EME2 use higher dosage (around 6.0-6.3%). It is interesting to observe that the Complex Modulus is mostly provided by the grade of bitumen and by the gradation curve of the mix. The resistance to the fatigue is ensured by a thicker film of bitumen around the aggregates characterized by the richness modulus (K) used (K > 2.5 for EME1 and > 3.4 for EME2)

3.3 Manufacturing and application

To achieve a good workability at the application the mixing temperature of EME should be around 180oC corresponding to the viscosity that provides good coating (0.2 Pa.s). Any type of mixing plant is suitable provided that the burner is set for this temperature.

Special care must to be brought to the performances of the platform or sub base whose bearing capacity has to be controlled. Due to the less thickness of the total bituminous structure, bounding become a key point that should be ensured with appropriate dosage of tack coat emulsion

Application is ensured with heavy table pavers equipped with tampers. They should be laid at high temperature to take advantage of the low mix viscosity between 160-180oC. Compaction is achieved with vibrating double steel roller and heavy tire roller compactor. A particular attention must be paid for transversal and especially longitudinal joint that can be done “hot on hot” to avoid weak points. Application in full width is recommended every time it is possible

Recommended thickness depends on the size of the chipping but also the structure design. Average thickness in place after compaction and lowest thickness in all point are given below:

EME type	Average Thickness	Minimal Thickness
EME 0/14	7 to 13 cm	6 cm
EME 0/20	9 to 15 cm	8 cm

3.4 Structure design

Road structure includes different layers whose thicknesses are calculated taking into consideration mechanical performances of each of them but also the level of traffic, increase of traffic over a certain period of time, load per axle, service life of the road, reference temperatures, frost and also safety factors. This method called “Analytical method” becomes the standard in many countries worldwide.

The trends in road structure consists to substitute base and binder courses by “EME” and top it with a thin overlay to privilege the safety of road users as it becomes a major concern for the time being: The EME2 for the structural impact, the overlay for safety (skid resistance and superficial water drainage)

The high level of stiffness modulus reduces the strain in mixes placed at lower levels that is favorable to the reduction of thickness under the same constrains of traffic. EME2 finally reduces cost of construction and maintenance but also preserve the environment by demanding less aggregate.

3.5 Field of use and perspectives

The particular market for EME is the one of new construction and re-enforcement of heavily trafficked roads with sometimes constrains of height in urban context:

- Heavy channeled and low speed traffic lanes such as bus lanes
- Special lane for very heavy traffic
- Wharf for loading
- Industrial and multimodal platform
- Urban and peri-urban roads
- Re-enforcement with height limitation
- Re-enforcement on expressway with limited depth of milling

The feedback of over twenty years’ experience is extremely positive as the increasing yearly tonnage can attest. These results from many trial sites and also numerous projects that never show any sign of failure after 10 and 15 years follow up. It has been evaluated the consumption of hard grade bitumen for EME in France last year to about 0.6 million tons of bitumen representing a potential of 8 million tons of EME among 47 million Tons of hot mix manufactured. The tonnage is in constant increase.

EME2 associated with thin overlay of 2-3 cm represents the most frequent maintenance technique for heavy trafficked roads. Combination of excellent mechanical properties (rutting and fatigue resistance), long lasting surface characteristics and long service life makes this technique one of the most cost effective for maintenance and re-enforcement on the market. This explains the nonstop development for urban roads.

The initial anxiety that road engineer had for using too hard bitumen was a certain sensibility to the thermal cracking and an increase of rigidity versus service life due to the hardening of already hard bitumen. Few singular cases of cracking have been clearly explained by the use of abnormally hard bitumen or the use of some additives and non-respect of the basic rules of application. Otherwise no cracks have been stated on the first sites after 20 years of service.

EME develop now in Europe (England, Belgium, Poland, Denmark) but also worldwide in Mauritius, Morocco, Madagascar, South Africa, Australia and French overseas departments (La Reunion, Martinique). Some other countries show strong interest as well such as South Africa and Australia which develop their own specifications adapted to the local context and reference temperature as these countries do not refer to the European specifications.

EME first major project in Australia in Brisbane

4 POLYMER MODIFIED BITUMEN FOR ASPHALT WEARING COURSE

4.1 Definition

Polymer Modified Bitumen “PMB” is a dispersion of polymer into the bitumen at high temperature under shearing. The composition and the selection of the polymer are made according to the performances expected and the economics as well.

The processing must be clearly defined in tests in laboratory and the different stages well described and respected once at the plant. These stages include pre heating bitumen, incorporation of the polymer, oil and eventually additives, mixing and/or crushing polymer, dilution with pure bitumen and maturation. This last stage is one of the most important because the polymer swells in absorbing some fractions (resins and aromatics) and this kinetic can take up to few days depending on the composition of the base bitumen.

PMB are now used in road industry for over more than 30 years and many authors have published about physical improvement and economic advantages. To summarize, the modification by synthetic polymer (SBS, SBR, EVA….) improves the physical properties at servicing temperature making the binder more flexible then reducing crack formation at negative temperature and much more consistent at service temperature (40 – 60oC).

Polymer can be classified in 2 families:

- Elastomeric (SBS – SBR – SEBS – SIS – PBD - Natural Latex – Crumb Rubber)
- Plastomeric (EVA – PE – PVC - Terpolymer)

Those polymers lead to different rheological properties and the selection is done according to the physical properties targeted and economic considerations.

4.2 SBS Modified Bitumen characteristics

The most widely used is the SBS (Styrene–Butadiene–Styrene) because of higher performances provided. It represents more than 80% of the PMB market. Performances are not proportional to the amount of polymer as many parameters have an influence on the final quality (type of polymer, type and origin of the bitumen).

SBS modified bitumen is manufactured by dispersing SBS polymer in the bitumen at high temperature and shearing.

The method of dispersion depends on the physical form of SBS used (pellet or powder). In both cases, the manufacturing temperature is highly important, as well as the duration of the process itself. These are the main parameters of the manufacturing process. A study of the formulation is mandatory and will of course include the traditional parameters such as penetration, Ring and Ball, as well as other parameters used to determine bitumen modification.

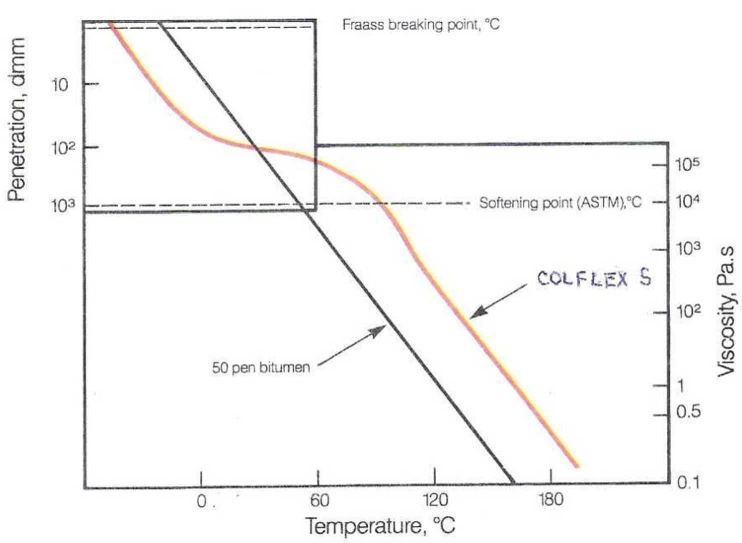


Figure 10.10 – Relationship between viscosity and temperature

Viscosity is also a critical parameter to better understand the interest of bitumen modification. Bitumen is like glue, with rheological characteristics (mainly viscosity) which vary as a function of the temperature. In fact, viscosity is what makes this product so interesting for the road industry, at room temperature, bitumen is highly viscous, thus ensuring stability for the mixes to which it is added, and at high temperatures, this viscosity is greatly reduced, thus enabling the bitumen to be pumped and dispersed in aggregate mixes.

The graph presented above demonstrates the effect of modifying bitumen with SBS polymers:

- Reducing viscosity at lower temperatures in order to make the bitumen less fragile.
- Increasing viscosity at ambient temperatures, i.e. increasing the Ball and Ring temperature.

4.3 Asphalt mix properties using SBS Modified Bitumen

Polymer modified Bitumen (PMB) has been developed to improve properties that normal asphalt cannot withstand under stringent constrains. Researchers have tried to link the properties of bituminous binders as measured in the laboratory to the actual performance of bituminous mixes on site, taking into account climate and traffic conditions. This was the key objective of the Strategic Highway Program (SHRP) designed in the USA around the late 80's, with the view to establishing performance-based specifications that would suit both pure and modified bitumen. Even though the so-called SHRP-SUPERPAVE system is being more and more widely used all over the world, its procedures and specifications still need further checks, particularly for modified bitumen. Moreover it does not provide a parameter for each function of bituminous mixes. Indeed we consider that the following table describes the parameters that should be taken into account to predict binder properties in relation to hot mix properties in Superpave system and also European Standard system:

Hot Mixes Properties	**Binder Parameters**	**Possible Tests**
Resistance to stripping by water	Adhesion	Adhesiveness (XPT66-043 - ASTM D 3625) Strength index (ASTM D1075 - ASTM D 6927) Duriez Immersion test (NFP 98-251-4)
Rutting Resistance	Performance Grade Softening point	Rutting tests at 60C (NFP 98-253-1) DSR after RTFOT (Performance Grade) (AASHTO TP5) Softening point (ASTM D 36)
Resistance to thermal cracking	Flexibility	DTT (AASHTO T314) Brittle point (EN 12593)
Hot Mixes Properties	Binder Parameters	Possible Tests
Fatigue Resistance	Auto recovery	DSR after RTFOT+PAV (AASHTO TP5) Fatigue Test (NFP 98-261-1) Elastic recovery (ASTM D 6084)
Durability	Resistance to ageing	Residual penetration after RTFOT + PAV (ASTM D 2872)
Resistance to Shearing Skid Resistance	Cohesion	Toughness Tenacity (ASTM D 5801) Pendulum Impact Test (EN 13588) CANTABRO test (NLT 352/86)

The following table shows the results for each of the above-mentioned tests for pure 35/50 pen bitumen and for 2 SBS-modified (at respectively 1.5% and 4%) binders of the same grade

PARAMETERS	INDICATOR *	PURE BITUMEN 30/50	SBS-MODIFIED BINDER 1.5 %	SBS-MODIFIED BINDER 4%
Adhesion	% of covered surface	50%	90%	90%
Complex modulus	T(°C) for G*/sinδ = 1kPa (DSR SHRP)	71.5°C	72.1°C	76.5°C
Flexibility - Cracking at low temperature	T(°C) for breaking elongation 1 % direct tension (SHRP)	-16.1°C	-19.5°C	-26.4°C
Fatigue Resistance Auto recovery	Elastic recovery at 10°C	Fragile (breaks upon elongation)	59.8%	89.0%
Resistance to Ageing	Residual penetration at 25°C after RTFOT + PAV	38%	not measured	57%
Cohesion	Conventional energy at breaking (5°C, 100mm/min)	< 10 J/cm2	16 J/cm2	33 J/cm2

*Indicators are all the better since the measured value is higher, except for breaking at low temperature, for which it is better when measured temperature is lower.

This table clearly demonstrates the added value of SBS elastomer for all parameters. It is important to mention that SBS action is significant at both high and low temperatures, whereas EVA polymers, which are sometimes also used as modifiers, only improve properties at high temperature and do not improve ageing resistance in the same proportion.

The other goal of SBS modification is to preserve good adhesiveness and improve asphalt mix fatigue behavior (resistance to repeated loads). Resisting high levels of deformation enables a modified asphalt mix to be applied in areas with high thresholds such as between curbs on city sidewalks or as reinforcement on sections crossed by bridges with limited height clearance. It can also enable the application of asphalt mixes on moderately deformable subgrades.

4.4 Field of use and perspectives

PMB is now widely use in substitution of even harder penetration grade bitumen for economics and safety:

- To optimize cost / service life
- To reduce maintenance frequency
- When constraints cannot be supported by conventional asphalt pavement
- To improve Safety of road users
- To reduce traffic noise
- For long lasting surface performances

In regards to the high performances provided, it can be used in places where pure bitumen cannot withstand high constrains such as shear stress, rutting, punching, fatigue, thermal cracking, crack rising….
It can be manufactured with higher penetration grades such as 35-50 or even 20-30. Some extra additives or polymer can be added regarding application targeted (for example Fuel Resistant PMB).

<u>Structural reinforcement:</u>

- Dedicated public transport lanes
- Special lane for heavy traffic
- Slopes, Roundabouts, Junctions
- Industrial platforms, facilities and multimodal structur
- Heavily trafficked road

<u>Airport</u>

- Aircraft parking Aprons and Runways
- Fuel filling Areas – Airplane parking

<u>Thin Overlay and Porous Asphalt for road</u>

- Reducing water projection and Aquaplaning
- Noise reduction
- High Skid resistance

<u>Wearing Course for specific area</u>

- Stresses areas, intersections
- High and Heavy traffic
- Orthotropic Steel Deck bridge
- Waterproofing

5 CONCLUSIONS

EME are a new and performing technique especially designed to face problems of constant increase of traffic aggressiveness and contributing to the sustainable development. The reduction of thickness induces significant saving of non-renewable resources.

The diversity of application is a major advantage of development thanks to more than 20 years' experience.

The transfer of technology by the French road authorities is already in place with several countries and EME technology thanks to the private road companies' exports in Europe, Maghreb and French overseas department.

Regarding the strong development of traffic and infra structures in Asia this could open new perspectives of fast development of this technology in short to medium term and a better use of natural resources.

SBS modified bitumen is not only obtained by defining its chemical composition, but also by determining its manufacturing process. Both elements confer specific characteristics to the modified binder.

SBS modified bitumen boasts the best performance results of all modified bitumen. They are used when conventional bitumen’s characteristics no longer suffice, in light of the pressure applied and required service life. Cohesion, elasticity and good ageing resistance are among this product’s most important qualities.

Combining these two technologies in pavement for base and wearing courses is the best way to ensure high quality and long lasting sustainable roads.

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