THE DEVELOPMENT OF A SOUTH AFRICAN HIGH STIFFNESS ASPHALT USING FRENCH EME METHODOLOGY

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ABSTRACT

For a considerable period of time, a type of asphalt mixture called high modulus mix (EME, Enrobé à Module Elevé) has become very popular in France in the construction of major roads and highways. EME, as a high modulus asphalt mixture, contains a very stiff binder that can be as hard as a 10/20pen. To ensure that the asphalt mix has good performance and durability, a mixture design is carried out and the performance properties, including compactability, water sensitivity, resistance to rutting, stiffness modulus and fatigue are measured and specifications in terms of stiffness and fatigue have to be met for EME qualification. Therefore, high modulus mixtures combine high binder content, good aggregate quality, high mastic content and low void content and the high stiffness is achieved with the use of a hard grade of bitumen. As EME's contain such a hard grade of bitumen, the manufacturing temperature is higher than standard asphalt products, approximately 180°C.
This paper describes how the high modulus mix has been developed, meeting the South African HIMA and French EME 2 specifications with aggregates, reclaimed asphalt product (RAP) and a 10/20pen grade bitumen that has been manufactured and supplied from a refinery in South Africa.
The paper discusses the binder and asphalt mix properties that are obtained and compares these properties to a typical French EME.

Keywords: Design Mix, Reclaimed asphalt pavement (RAP) Recycling, Stiffness

THE DEVELOPMENT OF A SOUTH AFRICAN HIGH MODULUS ASPHALT MIXTURE USING FRENCH EME METHODOLOGY

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ABSTRACT

Over the past thirty years a type of asphalt mixture called high modulus asphalt mixture (EME, Enrobé à Module Elevé) has become very popular in France in the construction of major roads and highways. EME contains a stiff binder that can be as hard as a 10/20 penetration grade. To ensure that the asphalt mixture has good performance and durability, an asphalt mixture design is carried out and the performance properties, including compactability, water sensitivity, stiffness modulus and resistance to rutting and fatigue are measured and have to meet stringent specifications for EME qualification. Therefore, high modulus mixtures combine high binder content, good aggregate quality, high mastic content and low void content. The high stiffness and fatigue resistance are achieved with the use of very good quality bitumen. As EME asphalt mixtures contain such a hard grade of bitumen, the asphalt production temperature is higher than standard asphalt products, approximately 180 °C.

This paper describes how a high modulus asphalt mixture has been developed to meet the highest level of French EME specifications (EME Class 2) using materials obtained from South Africa, with a 10/20 pen grade bitumen that has been manufactured and supplied from a refinery in South Africa and using local aggregates and reclaimed asphalt pavement (RAP).

Keywords: bitumen, EME, asphalt mixture, stiffness modulus, fatigue

1. INTRODUCTION

About thirty years ago, a technology was developed in France to obtain better mechanical properties for asphalt base layers in terms of stiffness and fatigue in order to construct durable, rut resistant and thinner asphalt pavements: Enrobé à Module Elevé (EME) or high modulus asphalt mixtures [1]. Since then such mixtures have been extensively tested in the laboratory, on test tracks and have been placed on many heavily trafficked main roads, major urban roads as well as on airport pavements in France [1,2,3].

An asphalt road is constructed with several layers designed to distribute and resist traffic induced stresses and strains. For the road user it is important to have safety, driving comfort and limited delays due to construction or maintenance works. From an asset value perspective, the design needs to take into account durability and lifetime of the pavement. Such a design requires information on the traffic, the expected growth in traffic (volume, axle load, tyre pressure), the local climate and asphalt mixture characteristics related to performance on the road. Furthermore, there is a need for the sustainable use of resources by considering the type of materials and the type of structures. Therefore, it is of interest to carry out full asphalt mixture design studies which include the determination of more fundamental characteristics related to performance such as fatigue due to repeated loading and stiffness modulus as a function of temperature and frequency.

High modulus asphalt mixtures are bituminous materials with high stiffness modulus, high resistance to rutting, good fatigue resistance and good durability. These mixtures will allow either the same design life to be achieved by reducing the thickness of the asphalt layers or a longer life to be obtained when using the same thickness determined by the conventional asphalt mixtures. As part of the compositional and constituent material requirements, the binder is a hard bitumen with a needle penetration value at 25 °C of 10 to 25 dmm (0.1 mm) and the binder content in the mixture is a key parameter to obtain high fatigue resistance and low moisture susceptibility.

In the last ten to fifteen years, several countries have shown interest in the technology, including UK [4], Belgium [5,6], Poland [7], Australia [8] and South Africa [9]. In South Africa, large increases in volumes of heavy vehicles on the road network are seen. One of the initiatives aimed at increasing the options available for the design of heavy trafficked road sections is the technology transfer project: HiMA T^2 project [9].

In the transfer of the French EME technology it is important to establish the translation to the local context in terms of materials, testing methods and applications.

In this paper the main results of a case study with materials from South Africa are presented: on the manufacturing and characterisation of a 10/20 penetration grade bitumen from SAPREF refinery in Durban as well as testing of EME Class 2 using aggregates and Reclaimed Asphalt Pavement (RAP) from South Africa. The asphalt mixture was prepared and tested according to the four level French mix design methodology. The laboratory study was carried out at the SHELL European Solution Centre in Strasbourg, France.

2. EXPERIENCE IN FRANCE

In France, until the beginning of the 1960s, asphalt mixtures were made with relatively soft bitumen, i.e. of the 180/220 or 70/100 (penetration) grades [1]. These mixtures performed well over a period of 15 years, but around 1965 several French regions, particularly in the south, began to experience creep and rutting problems. It should be noted that traffic had tripled between 1950 and 1965 and that the percentage of heavy-duty vehicles had increased by 60 %. Asphalt mixtures that supported 400 trucks per day without problems in 1950 were insufficient to resist 2000 trucks per day in 1965, thus leading to creep and rutting. These distresses manifested themselves on roads that were subject to heavy truck traffic, particularly in areas with long loading times.

Improvements in the mixture design were made taking into account the type of sand and the use of crushed aggregates as well as the use of harder bitumen grades with the production of 40/50 and 60/70 penetration grades.

One of the well-known asphalt mixtures which was developed at that time is the BBSG (Béton Bitumineux Semi Grenu ('semi' coarse) for wearing courses which provided high resistance to deformation, fatigue and low temperature cracking. Later on other solutions were developed, making use of the concept of differentiating layers in terms of structural and functional needs (thin surface layers and structural function for binder and base layers).

The maximum single axle load (weight per drive axle) in France is 130 kN, which is used as the reference axle load in pavement design. In most other (European) countries a lighter standard axle load (usually 80 kN) was adopted in the past, but more recently this was increased to 115 kN [2]. The choice in France leads to more aggressive traffic and, as a result, the weaknesses in pavement materials appear much more severely. This constant search for high performance has led to the use of even harder bitumen grades: 35/50, 20/30 and even 10/20.

In the 1980's, the high modulus asphalt mixture concept was developed and was standardised under the name of Enrobé à Module Elevé (EME) [1]. The EME innovation was made possible by extensive involvement from all participants in the road construction and management sector: road authorities, road contractors, laboratories and bitumen suppliers.

EME asphalt mixtures with a 10/20 penetration grade binder are used in base layers. The mechanical characteristics, particularly the higher stiffness modulus and good fatigue resistance, enable, with analytical pavement design, to reduce layer thicknesses as compared to the use of the conventional road base asphalt (Grave Bitume (GB) in the base layer). EME opened up the possibility to use thinner layers while having a high fatigue resistance so that the mixture can provide the same service life without premature structural maintenance and to use this material also in cases where there are layer thickness constraints for reinforcement or rehabilitation projects.

EME type asphalt mixtures for surface layers are also possible, in which case they are known as "Béton Bitumineux à Module Elevé" or BBME (high modulus asphalt concrete). In this case, a bitumen is used that is softer than the 10/20 penetration grade [1].

2.1 Asphalt mixture composition and characteristics

The aggregate composition of EME asphalt mixtures is generally 0/20, 0/14 or 0/10 and of the semi-coarse continuous type. The 0/14 curves are the most frequently used. The crushed stones and sand must have good resistance to wear and fragmentation. For example, in the Los Angeles abrasion test the loss value must be less than 30 % [10]. The particle size distribution and aggregate packing must be such that a rather low void content can be obtained with sufficient bitumen film thickness to obtain a durable mixture with good resistance to fatigue and cracking.
The European standard EN 13108-1 (derived from the previous French standards NF P 98-140 (for EME) and 98-141 (for BBME)) specifies the minimum characteristics for AC-EME Class 1 and Class 2, see table 1. These standards define these products not only in terms of composition, but above all in terms of performance (four levels of testing in the laboratory) [10].
In France, there are four levels used to characterise the EME Class 2 asphalt mixtures:

- level 1 on workability and water resistance
- level 2 = level 1 + rutting resistance
- level 3 = level 2 + stiffness modulus
- level 4 = level 3 + fatigue

A good water resistance as indicated by the Duriez test should exhibit a compression ratio (immersed/dry (i/C)) above 70 % for EME. Often higher levels have been found, although this ratio also depends on the nature of the aggregates. The workability and compactibility of the mixtures are assessed using the gyratory compactor press. Good resistance to deformation: in the wheel rutting test at 60 °C and 30000 cycles, the rut depth is generally less than 5 %. The stiffness is higher than for traditional materials, and the stiffness modulus at 15°C and 10 Hz is generally between 14000 and 23000 MPa. The good fatigue characteristics are derived from a two-point bending fatigue test on trapezoidal specimens at 10 °C and 25 Hz, without rest times, that gives values, at 1 million cycles, of 130 micro-strain and above.

Table 1: EME Class 1 and EME Class 2 specifications

Minimum characteristics of EME according to the European Standard EN 13108-1		
Performance	**Class 1**	**Class 2**
Percentage of voids with the Gyratory Compactor Press[a] (%)	≤ 10	≤ 6
Duriez test, i/C (%)	≥ 70	
Percentage of rutting, 30000 cycles at 60 °C (%)	≤ 7.5	
Stiffness modulus at 15 °C, 10 Hz (MPa)	≥ 14000	
Fatigue test at 10^6 cycles, 10 °C, 25 Hz (µstrain)	≥ 100	≥ 130

[a.] The results are determined at a certain number of gyrations depending on the nominal size of the aggregates.

The richness modulus, K, is a number which is related to the thickness of the bitumen layer around the aggregates [10]. To calculate the richness modulus, the binder content, aggregate density and the percentage of aggregates measured at the different sieve sizes, 0.063 mm, 0.250 mm and 6.3 mm sieves, must be known to estimate the specific surface area of the aggregate grading curve [10]. K is set at 3.4 minimum for EME Class 2.
From the analysis of many asphalt mixture design studies, it is known that the combination of a high stiffness modulus (≥14000 MPa) and a good fatigue resistance (≥130 µstrain) can sometimes be difficult to achieve [3]. It is a combination of good aggregate quality and skeleton together with the binder content and the quality of hard grade bitumen that provides the desired properties [3,6]. Furthermore, it is also important to take into account the reproducibility, not only the repeatability, of the measurements. In France a large scale round robin test was carried out for stiffness modulus and fatigue strength measurements, which are the values used in the European standards [3].
It is of crucial importance that the asphalt mixture design is carried out using the materials (aggregates, filler, bitumen) that are representative of those used in the field trials and road works.

2.2 Applications

The applications in which EME have been used include lanes for slow and channelled heavy traffic (buses and trucks), container terminals, maintenance of city roads, slow lanes on highways after milling with a limit of 8 to 12 cm milling depth [2]. In France the EME Class 2 in combination with a BBTM surface layer is often used for maintenance [2]. EME has also been applied on airports [2,11].
EME asphalt mixtures display the advantages of high stiffness and high fatigue performance, which for a given structure enable longer pavement life, or for a given lifetime allow thickness reductions in the order of 25 to 30 % compared to traditional flexible pavement [2]. The reduction in thickness still needs to be compatible with the summer and winter cycles (freeze/thaw) and frost protection [2].
In order to obtain a good performance on the road there are several precautions to consider.
In the asphalt plant the production temperature must be about 170 to 180 °C in order to have good coating of the aggregates and to have a laying temperature of about 150 to 170 °C [1,2]. The compaction needs to be carried out at a temperature higher than 140 °C [1]. The compaction needs to be done in such a way that the targeted density and voids content are obtained. The compacted asphalt mixture must fulfil this specification on the void content to get the high level of performance as based on the laboratory study.
In order to obtain a good bonding between the layers a tack coat is used which contains at least 250 g of residual bitumen per square metre [11]. By taking cores from the road the layer thicknesses and the bonding can be assessed.
As there is the possibility to reduce the thickness of the asphalt base layer with EME, it is important to take into account, in the pavement design, the variations in the load-bearing capacity of the foundation/subgrade layer [2]. Also, the average layer thickness must be respected and the variations in the layer thickness must be limited. In design calculations, this can be taken into account using a reliability factor. It is therefore essential for the roadbed to be prepared with great care. The average layer thickness as well as the minimal layer thickness must be respected for good structural functioning. Furthermore, particular attention has to be paid to joints.
A thin surfacing layer like BBTM (Béton Bitumineux Très Mince) of about 3 cm thickness is often used on EME which has been found to be a solution for France regarding the differentiation in the role of the layers and adapted to climate conditions [2].
In order to have good experience with EME it is important to respect the fundamentals: it is produced with high quality materials giving high performance, when applied with sufficient layer thickness, laid and compacted with respect to the asphalt mixture design and with very regular characteristics meaning without weak points (no segregation and thickness below the minimum requirement) [2].

2.3 Pavement design considerations and sustainability

The approach is to avoid fatigue cracking that propagates from the bottom to the top of the pavement and to avoid structural rutting. The maintenance for this type of distresses would often involve reconstruction of the whole pavement section. When each layer plays a distinct part in the overall road performance, the pavement design method must be able to take into account the asphalt mixture characteristics of each layer in the overall quality of the pavement.
As input there are the properties of the materials, material variability, seasonal variations, traffic and the limiting values against which the pavement responses are compared. In a probabilistic approach the designer can evaluate the percent of time that critical design values are below the threshold values. Layer thicknesses can then be selected according to the relative risk of exceeding these levels.
From the many roads built and monitored, it has been observed that significant reductions in the total thickness of the asphalt layers can be achieved with EME, up to about 25 to 30 %. As a result, much less material is necessary and the amount of aggregates transported and used can be considerably reduced [1,2]. Therefore, options for cost effective design can be considered with an efficient use of natural resources without compromising the desired performance of the asphalt layers.
Because of the performance properties a significant reduction in the pavement thickness or a substantial increase in the service life of the pavement for the same thickness can be obtained. The option of strengthening of an existing distressed pavement is especially of interest in cases where there are height (thickness) restrictions.
The French design guide for pavement structures [12,13] as well as the Highways Pavement Design Manual of Scetauroute [14] were used to make a comparison between the GB and EME structures [1,2]. As an example, in the case of the reinforcement of an existing road, it was possible to obtain a reduction in thickness in the order of 3 to 5 cm (using EME + BBTM in comparison with GB+BBSG) [2].
An extension of the service life of asphalt concrete roads will make it possible to have more economic maintenance scenarios with benefits to the road user in terms of improved safety and reduced congestion and delays.

2.4 Monitoring

The EME performance on the road is still regularly monitored and reported. The assessment of the behaviour of the sites with EME, often combined with very thin wearing courses (BBTM), is provided on the basis of monitoring operations and experience acquired by the scientific and technical network, "Réseau Scientifique et Technique" (RST), of the French administration [1,2].

Overall, the pavements with EME asphalt mixtures in France can be considered as performing well. Transverse thermal cracks have been observed in only a few cases. From the analysis, the thermal cracking was not considered an issue of the EME concept (in the French climatic context), but more related to operational issues [1,2].

2.5 Transfer of EME technology

Several countries have looked into the design philosophy of EME. In order to translate the concept to the local situation, several issues have to be looked into.

- Local availability of hard bitumen or hard binder grades.
- Integration in the local pavement design system to take into account the EME characteristics, also taking into account the climate conditions.
- To translate the French specifications and methods, which intrinsically are linked to the particular testing procedures in France, into locally available test instruments and test methods (for example two-point versus four-point bending test). In some cases parallel testing can be carried out between the country and France, using the country's binders and aggregates and based on French standards. This approach is followed in this paper and will be described in section III (case study).
- The production process of EME is in principle not different from that of conventional asphalt, with the exception that EME is mixed at higher temperatures to ensure proper coating of the aggregate with the viscous binder. Still, some adaptation and acceptance of the new technology will be required. For instance, dedicated bitumen tanks might be required as the bitumen will have to be heated to higher temperatures prior to mixing. Normal compaction equipment can be used as long as rolling techniques and compaction temperatures are carefully controlled. Care should be taken when compacting the layer to ensure that longitudinal cracks do not appear. In France, the compaction is carried out using very heavy Pneumatic Tyred Rollers (PTR) for a more homogeneous compaction within the layer. The target voids on the road site should be between 4 and 6 % for EME Class 2, which relates to a density of between 94 and 96 % of maximum theoretical relative density.

3. A CASE STUDY: AN EME FORMULATION WITH MATERIALS FROM SOUTH AFRICA

The aim of this study was to characterize an EME Class 2, using aggregate materials and a 10/20 penetration grade binder from South Africa, according to the testing sequence was carried out as defined in level 4 of the French mixture design methodology. The laboratory preparation and testing were carried out at the SHELL European Solution Centre, in Strasbourg, France, in 2014.

3.1 Bitumen

Samples of 10/20 hard grade bitumen, manufactured and supplied from SAPREF refinery in Durban, South Africa, were characterised in the laboratory. The bitumen properties have been determined according to EN test methods and they were compared with the EN 13924 specifications. The main results of the bitumen taken for EME asphalt testing are presented in table 2.

The penetration is close to the 20 dmm and the softening point is above 60 °C. The Fraass breaking point is -1 °C. After RTFOT, the increase in softening point is 7.8 °C.

Table 2: Properties of 10/20 bitumen sample

Tests		Unit	10/20 Bitumen from South Africa	EN 13924 specification
Penetration at 25 °C		dmm	18	10-20
Softening Point Ring&Ball		°C	61.2	58-78
Penetration Index		-	- 0.85	≥ - 1.5
Fraass		°C	- 1	≤ + 3
Solubility		%	99.8	≥ 99.0
Flash Point		°C	310	> 245
RTFOT	Change of mass	%	+ 0.01	≤ 0.5
	Retained penetration	%	72	≥ 55
	Increase in softening point	°C	7.8	≤ 8

The viscosity of the bitumen at temperatures above 130 °C was determined using an Anton Paar Physica rheometer MCR51. The temperatures at which the dynamic viscosity is 200 cP and 2000 cP are given in table 3. The viscosity of 200 cP provides guidance for the temperature for mixing and coating of the aggregates in the asphalt mixing plant.
The low temperature properties as measured in the bending beam rheometer (BBR) are also shown in table 3. The temperatures are shown at which the stiffness modulus is 300 MPa and the m value is 0.300.
Table 4 shows the G* and phase angle results from the DSR (Dynamic Shear Rheometer, Anton Paar MCR501) measurements at three different temperatures at a frequency of 0.4 Hz.

Table 3: Viscosity and BBR results of 10/20 bitumen sample

Tests		Unit	10/20 Bitumen from South Africa
Dynamic viscosity	200 cP	°C	173
	2000 cP	°C	133
BBR	T at which S = 300 MPa	°C	- 7.2
	T at which m = 0.300	°C	- 9.4

Table 4: G* and phase angle of 10/20 bitumen sample

	10/20 Bitumen from South Africa	
	G* (0.4 Hz), kPa	Phase angle
5 °C	94100	29
25 °C	4050	55
60 °C	5.7	85.7

3.2 Materials for asphalt and testing methods

The virgin aggregates, filler and a Reclaimed Asphalt Pavement (RAP) used for this study were sent from South Africa by the company National Asphalt.
The EME Class 2 asphalt mixture design was evaluated according to the following test methods as part of the French asphalt mixture design methodology [10]:

- Maximum asphalt mixture density according to EN 12697-5 in water.
- Gyratory compaction according to EN 12697-31.
- Water sensitivity test – DURIEZ method according to EN 12697-12 B.
- Wheel tracking test – large model in air according to EN 12697-22.
- Stiffness Modulus on trapezoidal specimens according to EN 12697-26 Appendix A (two-point bending).
- Fatigue test on trapezoidal specimens according to EN 12697-24 Appendix A (two-point bending).
- Soluble binder content by extraction according to EN 12697-1.
- Sieve grading according to EN 933-1.

Regarding the asphalt mixture formulation, the percentages of the different constituents were added according to the mixture recipe as given in table 5.
The total binder content of the EME was defined at 5.3 %, with a calculated richness modulus, K, of 3.50 which is 0.1 point above the French requirement for EME2. The binder content from the RAP was determined and contributed to 0.9 % of the overall asphalt mixture binder content. Therefore, 4.4 % of ‘fresh’ binder was added to the EME asphalt mixture.
The maximum density of the asphalt mixture was measured by the volumetric method in water. The measurements were taken with water at 25 °C after applying vacuum to the mixture to 30 mBar for 15 minutes in water. The calculated average value of the asphalt mixture density is 2.483 g/cm^3. This value was used to calculate the void content of the test specimens.

Table 5: Asphalt mixture formulation

Constituents	Hydrated Lime	C/Dust	10 mm	14 mm	RAP	10/20 Binder
(%)	0.9	32.2	8.5	34.0	20.0	4.4

A sub-sample was taken from the mixture in order to determine the binder content by solvent extraction and binder recovery. The extraction of the binder was carried out according to EN 12697-1 with an automatic bitumen extractor (infraTest Prüftechnik GmbH). A binder content of 5.4 % was measured for the asphalt mixture studied in the laboratory.

3.3 Asphalt mixture preparation

- The virgin aggregates were dried at 110 °C.
- The RAP fractions were dried at 90-100 °C.
- The aggregates and bitumen were heated to 180 °C in ventilated ovens.
- The RAP fraction was introduced into the virgin aggregates 2 hours before mixing as per the given protocol.
- Once the bitumen was at a mixing temperature of 180 °C, the aggregates were mixed for 30 seconds and then the bitumen was poured in the mixer and the whole material was mixed for another 300 seconds.
- Once mixed, the bulk asphalt mixture was covered and kept in an oven at 165 °C for 3 hours to simulate ageing during mixing at the asphalt plant and transportation to the road site. The asphalt was then reheated at 175 °C during one hour and compacted into a slab as per the given protocol.

3.4 Asphalt mixture testing

The asphalt mixture was first assessed in terms of workability and compaction with the LCPC type III Gyratory Compactor Press. The temperature during compaction was 180 °C and the voids determined at 100 gyrations were 6 %. The asphalt mixture was then assessed in terms of water sensitivity according to the DURIEZ method. Two sets of specimens were made from the same mixture; one set was conditioned in air at 18 °C and 50 % Relative Humidity for 7 days whereas the other set was conditioned in water at 18 °C. Both sets were then tested for compressive strength in a Compression Testing Machine (Cooper Technology) and the ratio of the averaged strength of both sets was determined (i/C). The results are presented in table 6.

Table 6: Duriez results

Properties	Results
Hydrostatic voids (%)	6.0
Bulk density (g/cm^3)	2.333
Strength after conditioning in air at 18 °C (MPa)	20.6
Strength after water immersion at 18 °C (MPa)	18.0
Ratio i/C (%)	**87.3**

In order to assess the resistance to permanent deformation of the EME Class 2 asphalt mixture, the wheel tracking test was carried out on two slabs of 100 mm thick. The repeated wheel loading was carried out for 30000 cycles at a test temperature of 60 °C. The results are presented in table 7 and in figure 1.

Table 7: Wheel tracking results

Properties	Results	EME Class 2 specifications
Test temperature (°C)	60	60 ± 2 °C
Average void content (%)	6.0	3 to 6
Rut depth at 30000 cycles (%)	2.0	≤ 7.5

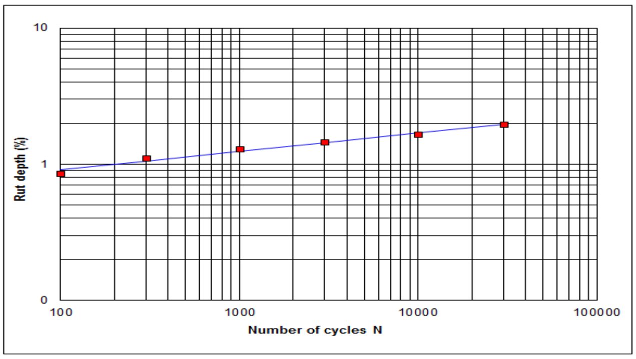

Figure 1: Ruth depth as a function of number of cycles

The stiffness modulus and the resistance to fatigue were both measured on a two-point bending machine (MLPC M2F). For the preparation of the slabs, the hot material from the laboratory mixer was poured in the pre-heated mould which was fixed to the slab compactor (LCPC compactor). Two days later, the slab was removed from the mould. The slab was then cut with an automated sawing machine to get 18 trapezoidal specimens. They were dried to constant mass and then the size (dimensions) and weight of each specimen were determined.
The specimens were fixed to the two-point bending apparatus as shown in figure 2. An eccentric motor allowed a sinusoidal displacement of the top of the specimens fixed to the apparatus. The amplitude could be adjusted on the motor. For stiffness modulus, the displacement applied to the top of the trapezoidal specimen was 30 microns to avoid damaging the specimen. For the fatigue test, which is a destructive test, the displacement ranged from 100 to 180 microns for the EME Class 2. The resulting force and displacement were measured during both tests.
The stiffness modulus tests were carried out at a test temperature of 15 °C and a frequency of 10 Hz. The test was repeated twice for each specimen and the average of eight specimen measurements is reported and presented in table 8.

Table 8: Stiffness modulus results

Properties	Results	EME Class 2 Specification
Number of samples tested	8	-
Average void content (%)	4.4	3 to 6
Stiffness Modulus at 15 °C, 10 Hz (MPa)	21650	≥ 14000
Stiffness Modulus Standard Deviation	1780	-

In total, eighteen specimens were used to carry out the two-point bending fatigue tests. The fatigue tests were carried out at a test temperature of 10 °C and a frequency of 25 Hz. The results are given in table 9.

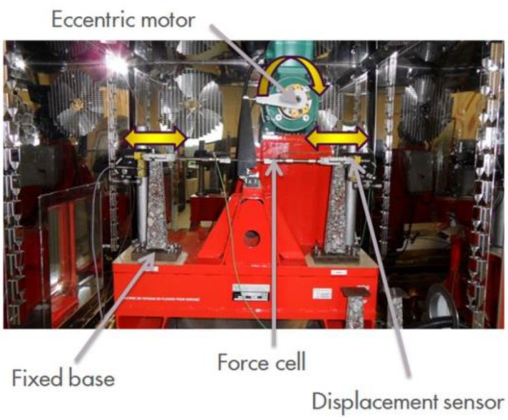

Figure 2: Two-point bending fatigue machine

Table 9: Fatigue results

Properties	Results	EME Class 2 Specifications
Number of samples tested	18	≥ 18
Average void content (%)	4.7	3 to 6
$\varepsilon_{6:}$ strain at 10^6 cycles, 10 °C, 25 Hz (µm/m)	130	≥ 130
$\Delta\ \varepsilon_{6:}$ quality index of the test at 95 % (µm/m)	4.9	-

3.5 Discussion

The results obtained in the asphalt mixture design using the French methodology show that the stiffness modulus of the asphalt mixture is much higher than the specification value and that the fatigue is just meeting the specified strain value. It has to be noted that given this high stiffness value and the presence of 20 % RAP, the fatigue resistance value still meets the EME Class 2 specified value. The results obtained with the asphalt mixture and the properties of the 'fresh' bitumen compared with the EN 13924, show promise in that it is possible to prepare a mixture that fulfils the French EME Class 2 specifications.
In order to optimise the asphalt mixture properties an option is to increase the total binder content by adding a little more virgin ('fresh') binder material which would reduce the stiffness and increase the value for the fatigue above the

specification level of 130 micro-strain at 1 million cycles. This will also ensure that with the inherent asphalt mixture control variability on bitumen content will still result in a suitable mixture.

The use of RAP in EME has been part of previous studies [9,15]. In a recent study in France, RAP was included in an EME asphalt mixture at rather high percentages. This study included the characterization of the binders with rheology and physico-chemical analysis on composition with SARA (saturates, aromatics, resins, and asphaltenes) and on degree of ageing with size exclusion chromatography and Fourier transform infra-red spectroscopy. A good homogeneity of the RAP is necessary in order to have comparable mixtures produced. It was also mentioned [15] that use was made of two separate drums in the asphalt mixing plant with one dedicated to the heating of the RAP. Although good results in mixture design and production have been obtained, with good performance after several years, the learnings and precautions need to be taken into account when developing further the application of the mixture with RAP in the asphalt mixture formulation. Indeed, the way the RAP materials are treated and the conditions under which they are mixed with the virgin materials have an impact on the asphalt performance.

In this asphalt formulation the contribution of the aged binder from the RAP has not been really studied and this should be a path to investigate in future formulations to balance the impact of the aged binder on stiffness and fatigue resistance.

4. CONCLUSIONS

The EME technology was developed in France about thirty years ago. These high modulus asphalt mixtures are successfully used on road sites for new pavements and for renovation and reinforcement. It is particularly dedicated to heavy trafficked roads with sometimes applications where road thickness cannot be increased. The long-term performance of EME asphalt mixtures is considered good.

On the basis of calculations on the pavement structure, the performance of high modulus asphalt mixtures enables reduction of layer thickness (by up to 25-30 % has been indicated in the literature) at equivalent pavement life [2]. This has to be locally determined, taking also into account the local climatic conditions. The benefits of EME can only be assessed when pavement design methods take into account the performance of the asphalt mixtures.

The laboratory results on the 10/20 pen bitumen and the asphalt mixture design show that a high modulus asphalt mixture can be produced with these materials from South Africa and that the asphalt mixture fulfils the French specifications for EME Class 2. The tested asphalt mixture formulation meets the requirements in terms of compaction, water sensitivity, resistance to permanent deformation and has a high stiffness modulus, well over the required EME Class 2 specification. As for the fatigue result, the strain at 10^6 cycles is right on the specification with a value of 130 micro-strain (for 1 million cycles). Although the bitumen stiffness was rather high and maybe accentuated in the asphalt mixture by the addition of RAP, this has not dramatically affected the fatigue performance. To validate these encouraging results, attention should be paid during the road application to the comments made about some of the observed road sites as indicated in the previous sections. Also a crucial point to consider for implementation is the representativeness of materials between laboratory study and road construction, production protocol with RAP and consistency of RAP.

Although the French mixture design framework has proved to correlate asphalt mixture performance between laboratory and field behaviour [10], the same verification process is in progress in the various countries where the technology transfer happens to account for different laboratory testing protocols and methods, different construction practices as well as climate and traffic conditions.

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