USE OF HIGH MODULUS ASPHALT – "EME"
CASE STUDIES IN THE INDIAN OCEAN AREA

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Abstract

EME (High modulus Asphalt) is a durable, deformation resistant, high performance base course mixture, based on established French technology according to NF EN 13108-1. The main characteristics of EME are improved rutting resistance, high stiffness modulus, durability thanks to high binder content and low void content, and they are obtained with the use of hard grade bitumen.

For more than 10 years, Colas companies in the Indian Ocean area (Madagascar, Mauritius, and Reunion Island) have been using EME for major projects for the construction of pavement for roads, airfields and port facilities using local materials.

These structures using EME layers are designed according to approved technical methods and provide the following advantages:

- Improved mechanical characteristics leading to pavement thickness reduction and resource preservation
- Financial savings and earlier completion time

The environmental benefits can be assessed using specific software which assesses the environmental impact of pavement construction: energy and greenhouse gas emissions.

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1 Background

1.1 Introduction

In the field of road construction, France has substantial experience with the use of base courses for pavements made from asphalt mixes with hard asphalt of class 35/50 or 50/70 called Road Base Asphalt (GB).
In the 1980's, the reinforcement work going through urban areas and for the restructuring of the slow lanes of highways and the increase in traffic volumes and loads on axles, led to the development of asphalt sub-base materials with better mechanical performances, allowing for the reducing of their thickness.
This led to the use of lower penetration binders in sub-grade courses in order to increase the rigidity (modulus) of structural layers. However, to compensate for the risk of premature cracking associated with the use of this type of binder as well as the risks of water resistance, higher binder content levels had to be used, which required the use of thinner materials.

High modulus Asphalt (EME) was therefore jointly developed at this time by the French road administration, asphalt producers and road construction companies.

This exclusively French technique is covered by a standard, NF P 98-140 (published in October 1992, revised in November 1999 and now obsolete) which provides for 2 classes of EME which were reiterated with the shift to the European standards in 2008 (NF EN 13108-1)
- Class 1 corresponds to road base asphalts with a high modulus (14,000 MPa) obtained by using hard asphalt, in dosages close to those of road base asphalts (GB).
- Class 2 corresponds to a high modulus asphalt mix which has, in addition, very good resistance to fatigue, given the high rate of pure binder. It is always this class 2 that we refer to when we speak of EMEs in general.

In order to reconcile two properties that are somewhat paradoxical, such as high modulus and high resistance to fatigue, a binder is used in a high dosage comparable to that used for asphalt mixes for surfacing. The high consistency of the mastic (asphalt + filler) associated with a low percentage of voids (3 to 5%) also yields very good resistance to rutting.

Since the end of the 1990s, High Modulus Asphalts have been used outside of France through technical cooperation between countries and road construction companies with an international dimension such as Colas.

1.2 Mix design and standard specifications of Enrobé à Module Elevé

The formulation method for asphalt mixes used in France is defined by the 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, such as EMEs, it can be classified in the "fundamental" approach.

High Modulus Asphalts observe 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 imposes specifications on the components and particularly the aggregate. It involves 5 tests which define the level of the study:

- 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 – NF EN 12697-31

The hydrocarbon mixture prepared in the laboratory is placed, expanded and at the test temperature, into a cylindrical mold. A vertical pressure is applied to the top of the test piece. At the same time, the test piece is inclined at a low angle and subjected to a circular movement. These various actions exercise a compacting pressure by kneading. We observe the increase in compactness (decrease in the percentage of voids) as a function of the number of rotations. For a given number of gyrations, a function of the type of asphalt mix, the nature of the aggregate and the laying thickness, the percentage of voids at the work site can be predicted.

Picture 1: Gyratory Compactor Press

The Duriez Water resistance test – NF EN 12697-12

The hydrocarbon mixture is compacted in a cylindrical mold by double-effect static pressure. Some of the test pieces are kept without immersion at a controlled temperature (18°C) and humidity level, the others are immersed. Each group of test pieces is crushed in simple compression.
The ratio of the resistance after immersion with the dry resistance gives the water resistance of the mixture.

The rutting test – NF EN 12697-22

The sample specimen is a 10 cm-thick parallelepipedic plate, depending on whether the applied thickness of the asphalt mix is less than or greater than 5 cm. This sample is subject to the traffic of a wheel equipped with a tire in severe temperature conditions. The depth of the deformation produced with the passing of the wheel is noted as a function of the number of cycles. The specifications cover a percentage of rutting with a given number of cycles, which depends on the type of material and its class.

The stiffness modulus – NF EN 12697-26

The rigidity of the mixture is determined either by a complex modulus test (sinusoidal stress on trapezoidal test sample) or by a uniaxial tensile strength test (on a cylindrical test specimen). The load is applied in the range of small deformations, by controlling the time or the frequency, the temperature, or the loading principle. The modulus (ratio of the stress to the deformation) is calculated for each elementary test. Thanks to the time-temperature equivalence, we can trace the principal contour of the modulus at a given temperature. This representation shows us the behavior of the mixture over a broad spectrum of loading times or frequencies. The specification covers the modulus at 15°C and a frequency of 10 Hz or a loading time of 0.02 s.

Fatigue resistance – NF EN 12697-24

A trapezoidal test specimen is subjected, at a fixed temperature and loading frequency, to an imposed deformation. When the stress applied to maintain the constant deformation is decreased by half, the test piece is considered to be damaged at the number of cycles in question.
On a log/log graph, the various couples (level of loading, number of cycles until damaging), are placed on a fatigue line. At 10^6 cycles, the loading threshold indicated on the line is the characteristic value of the resistance to fatigue: ε6.

Picture 2: Complex Modulus and Fatigue Resistance testing machine on trapezoidal specimen

Compared with the road base asphalt formulations, those for the EMEs are closer to those of thick asphalt mixes for wearing courses:

- The curve is generally continuous, containing 30 to 35% sand and 7% fines. The maximum dimensions are 10, 14 and 20 mm, but it is the 0/14 semi-coarse that is most often used. The objective is to obtain a rather dense material with few voids.
- The binder used is most often s straight run bitumen, much more rarely a modified bitumen or special asphalt, as defined in the standard NF EN 12591, developed by the oil companies and road construction companies.

Although no binder characteristics are imposed in the standard, it is most often appropriate to use 10/20, 15/25 or 20/30 asphalts, i.e. those for which the penetrability at 25°C is within the interval 10 – 30 (1/100 mm) and for which the Ring Ball temperature is close to 65°C, or higher.

Not all of the hard bitumen gives good results, particularly in terms of the stiffness modulus, and the choice of the binder is primordial for obtaining the characteristics of the standard. There is a relationship between the rigidity modulus G* of the bitumen measured with a rheometer and the complex modulus E* of the asphalt mixture. Oxidized hard asphalts generally have a low modulus G* even though they have a low penetrability and a high ring ball temperature. Experience shows that the stiffness modulus on the asphalt mix does not reach the values required for an EME.

The good resistance to fatigue is provided by a low voids content (on the order < 6%), and by a thick film of binder around the aggregate, characterized by a high binder content.

Table 1 presents a comparison of the standardized mechanical characteristics of the sub-base asphalt materials of particle size 0/14 (the most used), between the road base asphalt and the high modulus asphalt mixes.

	GB class 2	GB class 3	GB class 4	EME class 1	EME class 2
Binder content	> 3.8%	> 4.2%	No minimum	No minimum	No minimum-
Gyratory Compactor % voids at 100 gyrations	< 11%	< 10%	< 9%	< 10%	< 6%
Water resistance r/R	> 0.65	> 0.70	> 0.70	> 0.70	> 0.75
Rutting 60°C % rutting No. of cycles	< 10% 10,000	< 10% 10,000	< 10% 30,000	< 7.5% 30,000	< 7.5% 30,000
Module E* (Mpa)	> 9,000	> 9,000	> 11,000	> 14,000	> 14,000
Fatigue Ɛ6 (µdef)	> 80	> 90	> 100	> 100	> 130

Table 1: Comparison of the standardized mechanical characteristics

For the EME, the level of formulation in the laboratory is primordial in order to guarantee that the available constituents (aggregate and asphalt) will make it possible to reach the specifications of the standard. This long and expensive process must be followed each time we seek to use this technique in a new territory.

1.3 *Road pavement design method with Enrobé à Module Elevé*

French method

The official French method in effect, defined by the "Technical guide for the "Design Manual for Pavement Structures" from SETRA - LCPC published in December 1994 and used in the "Catalogue of standard pavement structures of SETRA / LCPC 1998" and updated in standard NF P 98-086 is an analytical method that takes into account the characteristics of the materials (modulus/fatigue).

The structure design principle is based on the comparison between the deformations or the maximum stresses calculated under the reference axle and the allowable limits of the materials that constitute the pavement. These limits are a function of the total of the loads that they are subjected to and of their mechanical characteristics; in the case of asphalt materials, they also depend on the average functioning temperature and the bearing capacity of the support layer.

The Alize-LCPC calculation program, established from the rules of the "Design Manual for Pavement Structures", LCPC / SETRA, allows us to determine, according to the principles of rheological behavior of the materials, their permissible limits for the total number of cycles of loading determined from the calculation hypotheses (resistance to fatigue).

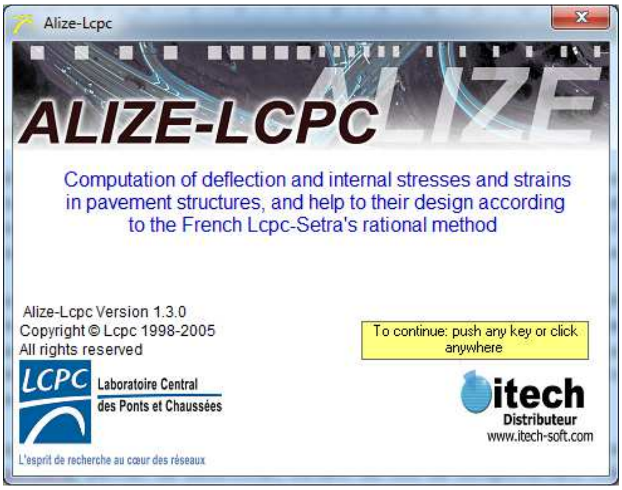


Figure 1 : Representation of the ALIZE LCPC software

The mechanical characteristics of the asphalt materials are linked to a functioning temperature which is weighted over the year, called the equivalent temperature, and to a frequency of loading linked to the speed of the vehicles: as a convention, for pavement design in Metropolitan France, the modulus at 15°C / 10 Hz, and the deformability at 10°C / 25 Hz are used. In the case of application to other territories, the equivalent structural design temperature must be calculated (generally the same as the average annual temperature).

The value of the complex modulus for an EME of class 2 thus passes from:

14,000 MPa at 15°C / 10 Hz to **11,000 MPa** at 20°C/ 10 Hz to **8,500 MPa** at 25°C/ 10 Hz

These values can also be adapted as a function of the frequency of the stresses and be taken at lower values (case of moving loads at low speed for ports or airports).

The value of the rational pavement design method is that it takes into account the optimized characteristics of the EME and thus allows for optimization of the thicknesses of pavement structures.

English method

The English method is mainly based on the empirical results from the interpretation of the behavior of certain road sections. However, due to the increase in the aggressivity of vehicles and traffic volumes, the TRRL (Transport and Road Research Laboratory) updated the principles of structural design for flexible pavements that are now included in the DMRB (Design Manual for Road and Bridges) and allowing for the use of higher performance materials.

The TRRL therefore drafted a complete report on the EMEs of class 2 of the French standard which were tested on a large scale in comparison with a standard Heavy Duty Macadam (HDM) in order to demonstrate the expected benefit for the United Kingdom, known in France for more than 25 years now.

Based on these very positive results, this material was then officially presented as a standard solution in DMRB HD26/06 (and according to method TRL615) as illustrated by the graph of figure xx.

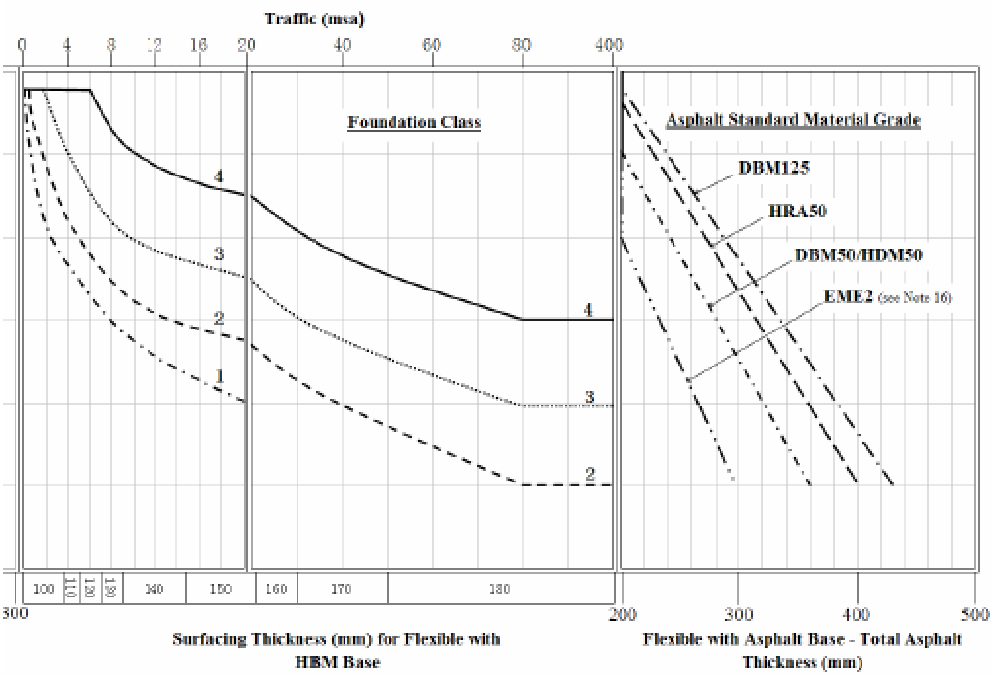


Figure 2: Excerpt from the graph DMRB HD26/06 "Pavement Design"

Thanks to this graph, compared to traditional material as DM or HDM, the use of Enrobé à Module Elevé can optimize the thickness of the pavement structure for more than 20 % for same levels of platform and traffic.

1.4 Airfield pavement design method with Enrobé à Module Elevé

French method

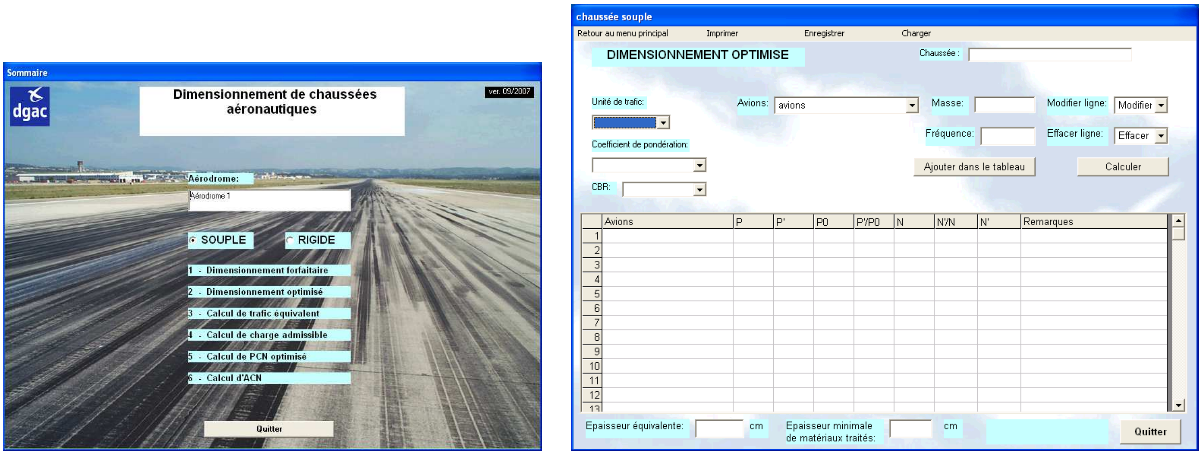


Figure 3: Representation of the DCA software

The official French method is established by the STAC (Civil Aviation Technical Service). The flexible structure is designed by the CBR method in which an equivalent theoretical thickness and a linked thickness of the materials are determined to protect the support soil under the repeated passage of the traffic.

These two minimum allowable thicknesses are determined with calculation charts (programmed since 2007 in the DCA software). Contrary to the rational French approach for road structure design, aeronautic structure design is purely empirical and the materials are distinguished by coefficients of equivalence.
The structure to be implemented was established by weighting the thicknesses of the layers by the corresponding coefficients of equivalence so that these two real thicknesses were less than the allowable thicknesses.

The coefficients of equivalence were determined for each type of material based on the American AASHO tests carried out in the 1960s in the United States. The mechanical qualities of the materials evolved, particularly with the introduction of high modulus materials. The STAC therefore carried out life-size experiments at the end of the 1990s in order to take these new materials into account in the pavement design method.
The new instructions thus define a coefficient of equivalence for EME allowing for the optimization of the pavement structures:

Materials	aeq
GB (road base asphalt)	1.5
EME (high modulus asphalt)	1.9

Table 2: Equivalence coefficient for DCA calculation

American method

The method developed by the FAA includes structural design calculation software called FAARFIELD. This method is not just used in the United States; it has been exported to many other countries.
The thickness to be used is determined by the finite elements method in which the structure design criterion is that the stress created under the most constraining landing gear is less than an allowable value which is dependent on the resistance to bending.
Each layer is characterized here by its modulus and its Poisson ratio. The pavement thickness is set so that the CDF (cumulative damage factor), i.e. the sum of the damage caused by all of the aircraft, is less than 1. For each aircraft, the surface deformation of the platform is calculated with a linear elastic model. From an empirical fatigue relationship, we can derive an allowable aircraft traffic level. The elementary damage associated with this aircraft is the ratio between the real traffic and the allowable traffic.

Figure 4 shows the typical structure given by the American method, the materials used and the associated rigidity moduli.

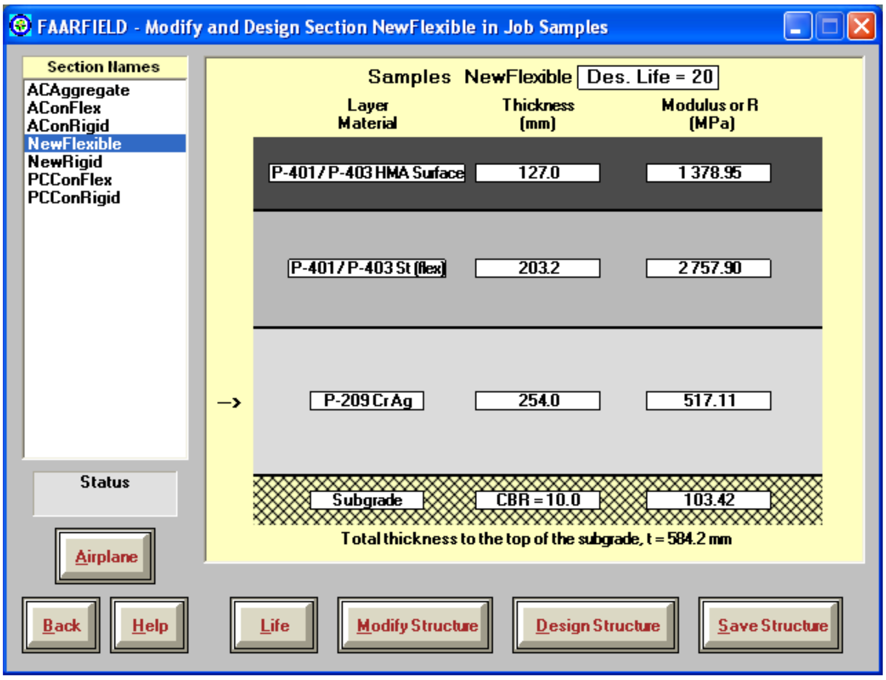


Figure 4: Representation of the FAARFIELD software

This approach is valuable firstly because the feedback from experience is substantial and also because it is based on rational considerations, even though empirical aspects remain. It makes it possible to take into account the real values of the moduli of the materials (as long as the temperature and frequency conditions to be taken into account are set) and to thus make use of EMEs.

2 Projects using EME in the Indian Ocean area

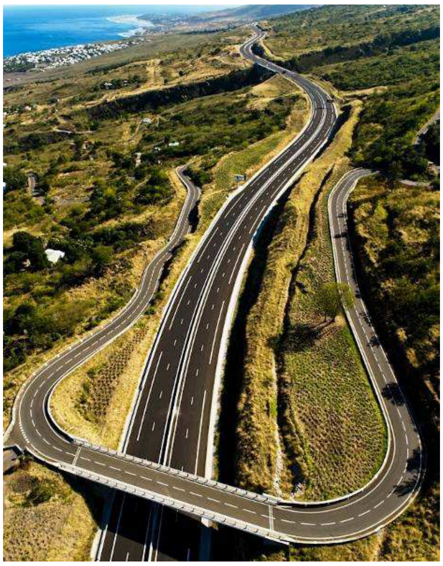
Colas Company has been present in the Indian Ocean for over 60 years now with permanent bases on all of the islands of the archipelago: Reunion, Mauritius, Madagascar, Mayotte and the Comoro Islands.

Thanks to the technical network of the Colas Group, High Modulus Asphalt Mixes have been "imported" for use in major projects in the Indian Ocean territories, with some adaptations to the local context: binder available in the refineries of the region, geological constraints and nature of the available aggregate, diversity of the standards and reference systems.

2.1 Road pavement: Tamarind Highway – Reunion Island

Reunion Island is a French Overseas Department. With a current population of 800,000 inhabitants and more than one million expected in 2020, there are many infrastructure needs. The Reunion Region decided in 2002 to build the "Route des Tamarins", in the West of the Island, the last link of 2x2 road lacking in the regional road network.

The construction of the "Route des Tamarins" highway was a major project. Thirty kilometers of standard 2 x 2 lane sections and 500,000 tons of asphalt mix were the initial figures, but the specificity of this project lies in the exceptional density of the obstacles to be crossed with more than 30 ravines including three that are crossed by exceptional civil engineering structures.



Picture 3: Aerial view of the work site

As Reunion is a French region on the administrative level, the standards and reference documents that apply are the same as those of Metropolitan France, i.e. the European standards for the products and the pavement design methods of the LCPC / SETRA.

The pavement structure for the project is composed of sub-grade courses (Foundation + base) made of High Modulus Asphalt (E.M.E. 0/14 cl.2), a product which was not so widely used locally, but for which the use became standard with this project.

Course	*Nature of the materials*	*Thickness*
Wearing	*Very Thin asphalt concrete 0/6*	*2.5 cm*
Binder course	*Semi-coarse asphalt concrete 0/10 cl. 3*	*6 cm*
Base	*EME 0/14 cl.2*	*9 cm*
Road base	*EME 0/14 cl.2*	*10 cm*
Adjustment	*Crusher-run gravel 3 (0/20)*	*10 cm*
Platform PF	*Crusher-run gravel 1 (0/63)*	*Ev2 > 100 MPa*

Table 3: Pavement structure of standard sections

In the preliminary pavement structure studies, the client initially chose to use a traditional Bituminous Base Asphalt ("Grave Bitume" class 3) for the base courses, an asphalt mix commonly used on Reunion Island. The pavement structure was then 4 cm thicker (12 + 12 cm of GB3). The client therefore chose EMEs in order to optimize the costs and to preserve the aggregate resources of the island.

There were several constraints linked to the project for developing the EME formula:

- The climatic aspect

In order to design the pavement structure as accurately as possible, the reference temperature for the calculations with the Alize LCPC software was set at 20°C instead of the usual 15°C in Metropolitan France. The complex moduli of the asphalt mixes were therefore chosen for this temperature, which increased the pavement structure by 1 cm compared with the usual structures of the catalogue of pavement structures of the French national road network.

- The geological data

The Reunion basalt used for road construction has particular characteristics and sometimes requires a different approach for the formulation of mixtures, particularly for hydrocarbon mixtures:

- The intrinsic characteristics are excellent despite a macro porous visual appearance. Some of the bitumen of the mixture is absorbed by the aggregate, which implies additional doses on the order of 0.3 to 0.7 % in the formulae compared with the usual binder content levels in order to guarantee the mechanical performances of the asphalt mixes.
- The aggregate produced is also very abrasive, a phenomenon which is revealed by a lack of workability in the Gyratory Compaction Test (NF EN 12697-31) with void percentage values that are at the limits of or even outside of the specifications although the compactness is easily obtained in situ. With this type of material, the resistances to rutting results are often excellent however.

- The logistical aspects

The issue of the availability and supplying of the hydrocarbon binder is quite different in the particular context of Reunion Island: the storage capacities on the local scale are insufficient for such a project. The search for a binder adapted to EMEs near the region was a real challenge.
A solution was found in the South African refineries of Durban (Engen in particular) which were able to supply a hard binder of class 20/30 which made it possible to obtain the characteristics that were sought.

The formulation of an EME 0/14 cl. 2 level 4 meeting the requirements of the contract required more than three years of research and seven alternatives were made starting in 2004 by the various asphalt mix departments of the COLAS Scientific and Technical Campus in Magny les Hameaux. The main issue for obtaining the modulus and the fatigue resistance in compliance with the specifications of the standard was finding a hard binder that was suitable (20/30) and available in the Indian Ocean zone and also the optimal gradation curve with the aggregate at our disposal.

Formula EME 0/14 cl 2	Composition	Comments
Gradation cut-offs	0/4 – 4/6 – 6/10 – 10/14	Optimized curve
Asphalt	20/30 South African	Binder content 6.25 %
	Results Study level 4	Specifications CCTP / NF P 98-140
RSP Test Voids content at 100 gyrations (%)	5.4	≤ 6
Duriez Test R (MPa) Ratio r (Mpa) / R (MPa)	21.3 0.82	≥ 0.80
Resistance to rutting Voids content Gamma Bench (%) Rutting at 30,000 cycles 60°C in %	5.3 5.5	3-6 ≤ 7.5
Complex modulus Voids content of test pieces (%) E* 15°C 10Hz (MPa)	5.0 14,022	3-6 ≥ 14,000
Resistance to fatigue Voids content of test pieces (%) Resistance to fatigue ε6 10°C 25 Hz (µdef)	3.0 130	3-6 ≥ 130

Table 4: Performances of the EME 0/14 class 2

The many studies were justified by the change of the crushing station of the supplier in 2007 and by the search for the optimal binder content to obtain the compliance of all of the mechanical performances.

Picture 4: Laying of EME on crusher-run gravel layer

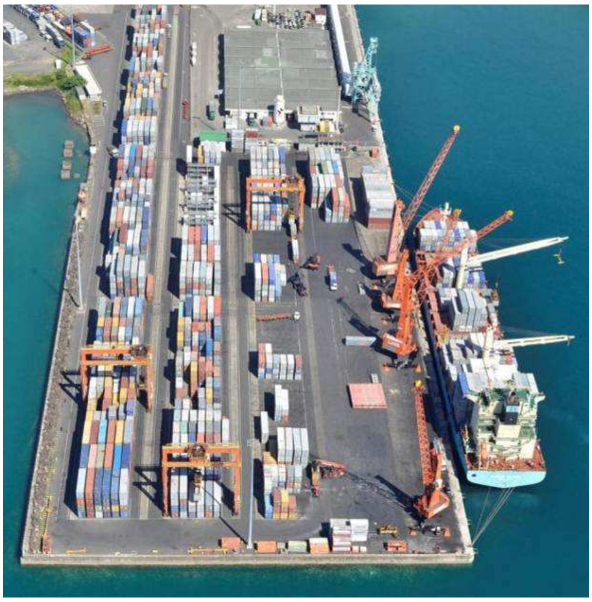
In the end, close to 350,000 Tons of EME were used for this project with strict quality control: systematic verification of production (binder content and respect of the reference gradation curve and the laying by in situ void content control).

This project constitutes a highway reference in the Indian Ocean zone and it did indeed allow for the development of EME in the neighboring territories because of the substantial research carried out.

2.2 Tamatave Port – Heavy structures – Madagascar

Renovation of the container terminal

At the end of the 2000s, Madagascar assigned the concession for the container terminal of the main port of the country to a Philippine company, M.I.C.T.S.L. In order to improve merchandise handling, this new management company decided to renovate and modernize the entire terminal over more than 70,000 m².



Some of the work included the reinforcement of pavement structures. The base solution from the manual of the British Port Authority was composed of a semi-rigid structure of cement bound aggregates and asphalt mix surfacing. The drawbacks of this solution were that it required excavating and planning the existing structure.

Colas Madagascar proposed an alternative asphalt mix solution. The Technical Department of the company carried out a complete auscultation of the various work zones: a campaign of deflection and core drillings which revealed an existing asphalt mix structure varying from 10 to 16 cm and presenting an area very polluted by hydrocarbons.

Picture 5: Aerial view of the Port of Tamatave

The alternative structure was designed by the Expertise and Documentation Center of the Colas Group and involved:
- Planing the existing surfacing over 4 to 5 cm in order to provide an adequate support
- Laying special asphalt mix reinforcement:
    - Base course of EME class 2 of a variable thickness of 12 to 16 cm
    - Wearing course of high modulus asphalt concrete of 6 cm

Base Solution BPA	**Alternative Solution COLAS**
100 mm semi-course asphalt concrete	**60 mm high modulus asphalt concrete**
390 mm CBM 3	**120 to 160 mm EME2**
Subgrade CBR > 10 %	Existing Pavement

Figure 5: Comparison of the structures

The traffic of the road and platforms of the port is composed of:
- Trucks transporting containers
- Stacker type handling machines with a front axle of 100 Tons when fully loaded

The pavement design calculations were done using the Alize software and in accordance with the French structure design method which takes into account the weight of the axle and the number of movements of the vehicle.

The High Modulus Asphalt Mixes were made with a TSM 15 Ermont type mobile plant with basalt-origin aggregates from a local quarry and 20/30 hard asphalt from South Africa.

This alternative solution offered numerous advantages: rapidity and flexibility of execution, with the terminal remaining in operation throughout the work and above all it was economical because the existing structures were partially conserved.

Renovation of the platform for boat lift

In the continuity of the work carried out at the Port of Tamatave, Colas Madagascar also did renovation work on the heavy pavement platform intended to receive a boat lift, for taking boats out of and putting them back in the water.

A study carried out by the client led to the proposal of a rigid type structure composed of cement bound aggregate type sub-base materials of class 3 over 100 cm and cement concrete surfacing of class 5 of 20 cm thickness.

The other types of heavy pavement and particularly asphalt pavements were ruled out because "their application can require the use of materials or techniques which are not always well suited to the local context."

Picture 6: Boat lift and EME platform

Having renovated the container platforms of the Port of Tamatave and having a certain perspective and good experience with the use of special asphalt mixes, Colas Madagascar proposed an alternative solution for this heavy pavement by using High Modulus Asphalt Mixes for the base courses and an Anti-fuel asphalt mix for the surfacing.
The pavement design was done according to the French method defined in the Structure and Thickness Design Guide of the LCPC/SETRA with the hypotheses presented hereafter.

In order to take into account the displacement of the vehicle at low speeds and the tropical climate of the city of Tamatave, the moduli of the asphalt mixes are those obtained at 25°C and 3 Hz.

Material	Modulus (MPa) 25°C / 3 Hz	Resistance to fatigue ε6	Poisson Ratio
High modulus asphalt concrete Anti K	5 500	/	0.4
EME class 2	6 000	130.10-6	0.4
Pit-run gravel 0/31.5	360	/	0.35
Pit-run gravel 0/60	E = 3 x EPF = 150	/	0.35
Support platform PF2	50	/	0.35

Table 5: Characteristics of the materials in the work site context

The reference vehicle is a boat lift with the following characteristics:

- Empty weight: 120 Ton – Maximum weight to be lifted: 300 T distributed over 4 supports with a front / rear distribution of 40 % / 60 % or 90 tons maximum for a rear post. Each post rests on 2 dual wheels.

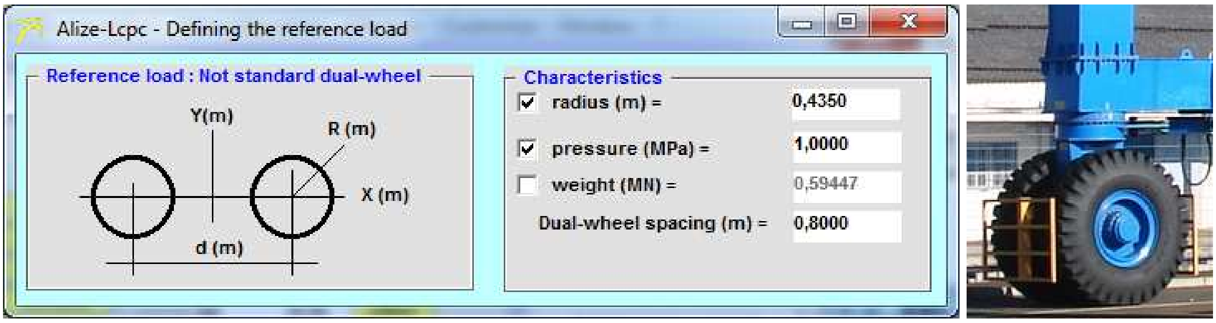


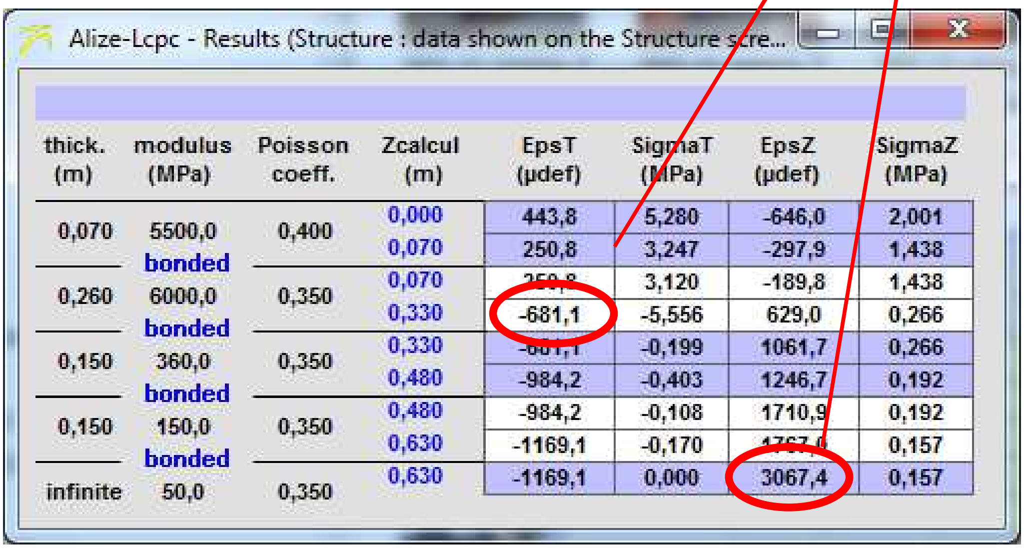
Figure 6: Modeling in Alize LCPC of the non-standard load of the lifting machinery

Based on these hypotheses, the limits allowed by the materials are calculated by the software.

Materials	Traffic Eq	Permissible limits
E.M.E. 2	NE = 1 417 e.s.e*	εt ad = 779 10-6
Pit-run gravel & new platform		εz ad = 3194 10-6

Table 6: Permissible limits *e.s.e: standard axle equivalents

The modeling of the structure with the Alize LCPC software gave the following result:


Alize-Lcpc - Results (Structure : data shown on the Structure scre...

thick. (m)	modulus (MPa)	Poisson coeff.	Zcalcul (m)	EpsT (µdef)	SigmaT (MPa)	EpsZ (µdef)	SigmaZ (MPa)
0,070	5500,0	0,400	0,000	443,8	5,280	-646,0	2,001
			0,070	250,8	3,247	-297,9	1,438
	bonded						
0,260	6000,0	0,350	0,070	250,8	3,120	-189,8	1,438
			0,330	-681,1	-5,556	629,0	0,266
	bonded						
0,150	360,0	0,350	0,330	-681,1	-0,199	1061,7	0,266
			0,480	-984,2	-0,403	1246,7	0,192
	bonded						
0,150	150,0	0,350	0,480	-984,2	-0,108	1710,9	0,192
			0,630	-1169,1	-0,170	1767,0	0,157
	bonded						
infinite	50,0	0,350	0,630	-1169,1	0,000	3067,4	0,157

Figure 7: Pavement structure modeled in Alize LCPC

The deformations calculated are lower than the allowable deformations.

The structure is thus verified according to the calculation rules.

This alternative solution made it possible to reduce the thickness of the heavy pavement from 120 cm of treated material for the base solution to 63 cm, for savings on the order of 50 %.

The use of High Modulus Asphalt Mixes also allows for savings of time in the execution because the reopening of the platform to traffic is almost immediate, unlike the situation for materials treated with hydraulic binders which require a drying and setting time of several days or even weeks.

2.3 SSR Airport – Airfield Pavement - Mauritius Island

The Runway Overlay and Parallel Taxiway Projects were funded by Airports of Mauritius Co Ltd (AML). The contracts were granted to the COLAS - Rhem-Grinaker Joint Venture. The pavement works were handled by COLAS with a dedicated work team and equipment supported by the COLAS Indian Ocean network. All of the skills of the COLAS Group including those at the corporate level were used for all technical matters of both projects, particularly the alternative pavement design.

Picture 7: Aerial view of SSR International Airport

The Runway Overlay project (value 25 Million Euros – duration 12 months) included:

- Overlaying the existing runway over a length of 3,370m
- Widening of existing shoulders by 7.5m on each side
- Reconstruction and widening of existing turn pads, reconstruction of Taxiway A
- Extension of the existing Runway End Safety Area (RESA) and Blast Pad
- Replacement of Aeronautical Ground Lighting, illuminated signage and markings

This work was done during a series of temporary overnight closures of the runway. During this period and for all flights, the runway was closed each night from 10 pm to 6 am. The pavement works were completed in June 2012, 3 months ahead of scheduled.

The Parallel Taxiway project (value 40 Million Euros – duration 18 months) included:

- New construction of a Code F compliant Taxiway, 2,300m long x 60m wide and associated exit links
- Construction of an Isolated Parking Pad, construction of a 60m x 90m Runway End Safety Area (RESA)
- Replacement and repairs of existing damaged taxiway and apron slabs
- Construction of a Final Approach and Take-off Area (FATO)
- Installation of aeronautical/approach lighting
- Perimeter road and other ancillary works

This Taxiway is also planned to be used as an Emergency Runway on completion. Most of the works were carried out during the day, from 7 am to 6 pm. The final works were completed in March 2013, 3 months ahead of the contractual deadline.

	Runway Overlay	Parallel Taxiway
Earthwork	150 000 m3	1 800 000 m3
Crusher Run	30 000 MT	110 000 MT
Cement Bound Material	-	70 000 MT
Asphalt concrete	100 000 MT	120 000 MT

Table 7: main quantities

All of the necessary equipment used for both projects was installed close to the worksite: stone crushing plant, stabilizing plant for CBM, asphalt plant. Offices and a fully-equipped laboratory for quality control were also installed. More than 300 staff members worked on both projects.

Picture 8: aerial view of plant area

Alternative Pavement Design

COLAS submitted alternative pavement structures in its offer, mainly for the new taxiway link and the new parallel taxiway construction.

These alternatives are based on the use of innovative Hot Mix Asphalt: Enrobé à Module Elevé "EME" for the Base Course instead of using Pavement Quality Concrete or traditional Bituminous Bound macadam base.

Pavement designs were made according to the US Federal Aviation Administration (FAA) method, using the FAARFIELD software, following the Advisory Circular 150/5320-6E Airport Pavement Design and Evaluation. The studies were done by COLAS design experts from the "Campus Scientifique et Technique" (COLAS Corporate Research Center).

Alternative structures were designed so that the pavements could bear the same aircraft movements (including A380) expected for the next 20 years. For the alternative design, due to the high temperatures in Mauritius and the low frequency of solicitation, the modulus values are reduced to the following values:

Method	Faarfield stiffness
Marshall Asphalt	1 400 MPa
EME2 *	6 000 MPa
CBM P304	3 450 MPa

Table 8: Stiffness of material

Calculation for New Taxiway Link:

	Taxiway Link – Subgrade CBR > 9	
Course	**Basic design**	**Alternative design**
Wearing	100 mm Marshall Asphalt	50 mm Marshall Asphalt
Binder	75 mm Asphalt Binder	210 mm EME
Base	370 mm Concrete	150 mm Cement Bound
Sub Base	150 mm Granular	100 mm Granular
	695 mm	510 mm

Table 9: Comparison between the basic and alternative designs

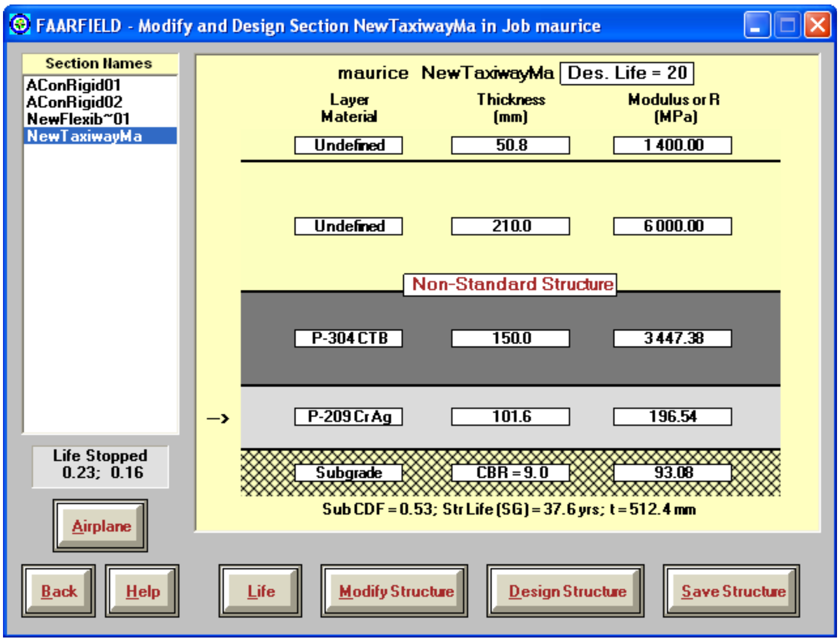


Figure 8: Pavement structure modeled with Faarfield software

Calculation for New Taxiway:

	New taxiway - Subgrade CBR > 15	
Course	**Basic design**	**Alternative design**
Wearing	125 mm Marshall Asphalt	50 mm Marshall Asphalt
Binder	75 mm Bit. Macadam	120 mm EME
Base	175 mm Cement Bound	150 mm Cement Bound
Sub Base	150 mm Granular	100 mm Granular
	525 mm	420 mm

Table 10: Comparison between the basic and alternative designs

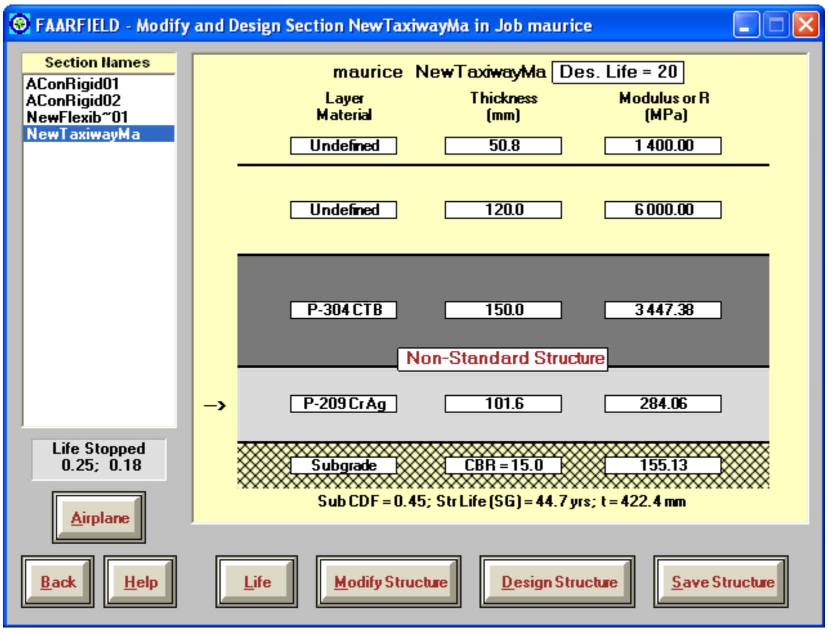


Figure 9: Pavement structure modeled with Faarfield software

The Job mix formula was made using local aggregates from a quarry (basalt) and grade 20/30 bitumen from a South African refinery in Durban.

Environmental assessment

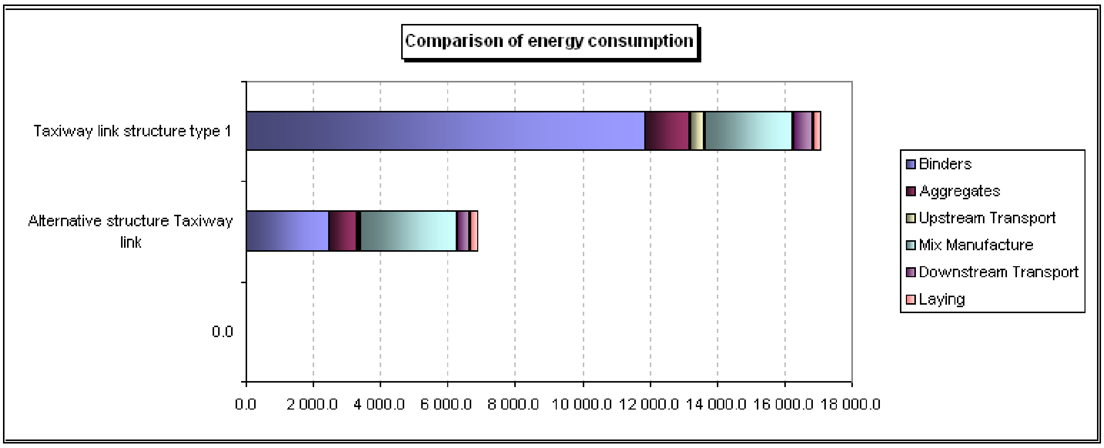
The environmental benefits were assessed using the "Ecologiciel ®" software developed by COLAS. Ecologiciel ® assesses the environmental impact of road construction: energy and greenhouse gas emissions.

This software calculates the contribution made by road construction in terms of energy consumption and greenhouse gas emissions. The entire production and construction process is taken into consideration, from the extraction of raw materials and the manufacturing of the products to the end of construction.

For the alternative pavement design proposed in this report, the environmental benefits in reducing the thickness of the structure can be summed up in 2 points:
- Optimizing the use of raw materials and reducing energy consumption.
- Reducing the impact of Greenhouse gas emissions.

Taxiway link: Basic structure compared to alternative structure

Comparison of energy consumption: - 59.5 % i.e. 10 170 Giga Joule



Comparison of GHG emissions: - 78 % i.e. 1 481 Ton equivalent CO_2

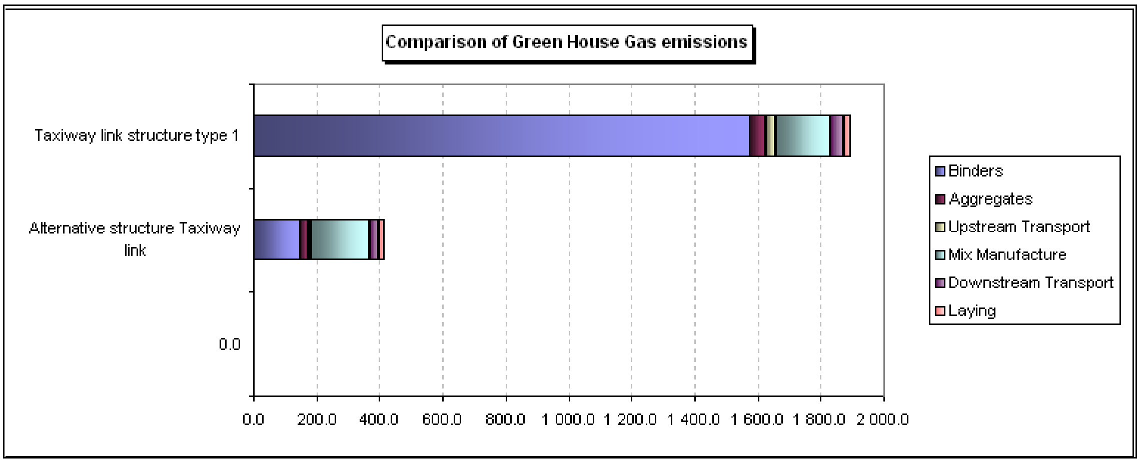
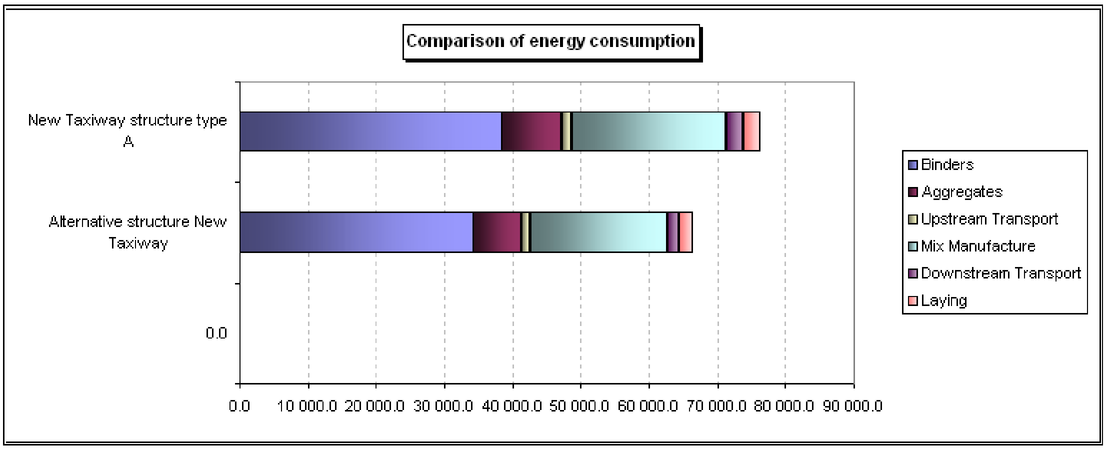


Figure 10: extract from Ecologiciel software

New Taxiway: Basic structure compared to alternative structure

Comparison of energy consumption: - 12.8 % i.e. 9 778 Giga Joule



Comparison of GHG emissions: - 13 % i.e. 837 Ton equivalent CO_2

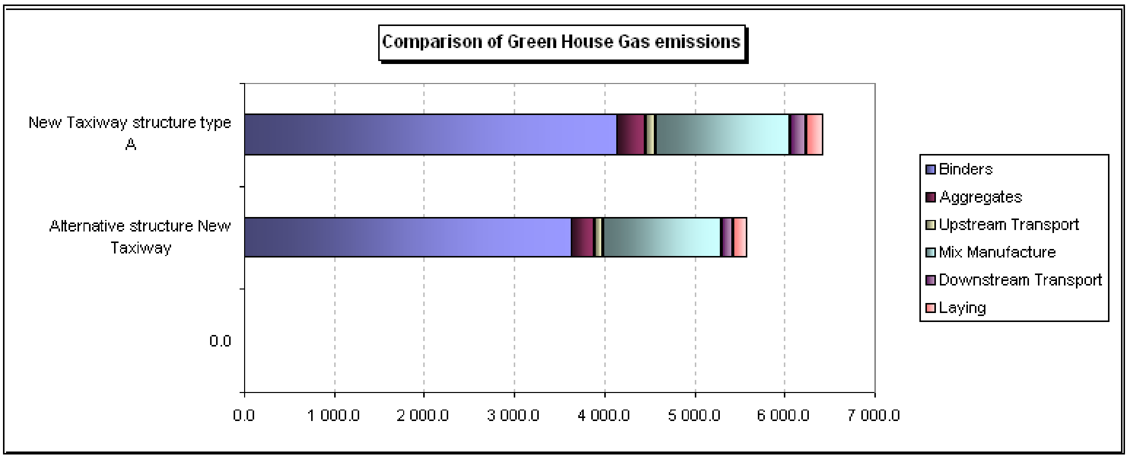


Figure 11: extract from Ecologiciel software

Alternative structures have led to the following savings: 20 000 Giga Joule and 2300 Ton equivalent CO_2.

The total savings from the alternative proposals represent the energy equivalent of:

- About 6 250 000 km covered by an average light vehicle i.e. 160 times the circumference of the earth!!
- More than 800 return trips by plane between Europe and Mauritius.

Alternative structures using EME layers provide the following advantages:

- Improved mechanical characteristics leading to pavement thickness reduction and resource preservation (crucial issue for small areas like Mauritius island)
- Easy installation and lower maintenance requirements
- Financial savings (8 % of the cost of pavement structure)
- Earlier completion time (3 months for each project)

2.4 Other developments

South Africa

Since the middle of the 2000s, the Southern African Bitumen Association (Sabita) has been encouraging the development of High Modulus Asphalt Mixes in South Africa based on a transfer of technology with Europe. Starting in 2008, a mission of experts was carried out with European road construction companies (including Colas) and suppliers of asphalt (Total and Shell) in order to study the feasibility of the transposition of this technique. Comparative tests were then carried out between South African and European laboratories with local binders (particularly the 20/30 Durban asphalt already widely used in the Indian Ocean zone and aggregate from local quarries).

The goal of these studies was to transpose the method of formulation of the European standards with the tests carried out locally and also to define specifications for the performances to be reached for the "HiMa". This synthesis work carried out by the CSIR and published in an "Interim guide for the design of high modulus asphalt mixes and pavements in South Africa" was presented during the CAPSA conference in 2011.

Parameter	French test method	Selected South African equivalent
Workability	EN 12697 - 31: Gyratory compactor	ASTM D6926: SUPERPAVE gyratory compactor
Durability	EN 12697 - 12: Duriez test	ASTM D4867: Modified Lottmann test
Permanent deformation	EN 12697 - 22: Wheel tracker	AASHTO 320-03 SUPERPAVE shear test
Dynamic modulus	EN 12697 - 26: Flexural beam	AASHTO TP 62 dynamic modulus
Fatigue test	EN 12697-24: Prism	AASHTO T 321 Beam fatigue

Table 11: French performance tests and selected South African equivalents

Property	Test	Method	Performance requirements for class 2
Workability	Gyratory compactor, air voids after 45 gyrations	ASTM D6926	≤ 6%
Moisture sensitivity	Modified Lottman	ASTM D4867	Min TSR 0,8 Wet climate High permeability
Permanent deformation	RSST-CH, 55°C, 5 000 repetitions	AASHTO T 320	≤ 1.1% strain
Dynamic modulus	Dynamic modulus test at 10 Hz, 15°C	AASHTO TP 62	≥ 14 GPa
Fatigue	Beam fatigue test at 10 Hz, 10°C, to 70% stiffness reduction	AASHTO T 321	≥ 410 με for 10 E6 reps

Table 12: Tentative performance criteria for HiMA bases

A Test project was carried out in 2011 in Durban on a high-traffic pavement going to the Port zone. The follow-up at one year showed very good behavior of the base course. The development of EMEs in South Africa must now be reinforced by the taking into account of this technique in the official structural design method.

New Caledonia

New Caledonia is a Pacific island which has the status of an Overseas Province under French jurisdiction. The standards and practices draw on French reference systems. The High Modulus Asphalt Mix Technique is also widely used in this territory.

Despite many research projects and formulation studies, up until now the asphalts available in the Asia zone were not satisfactory in terms of the complex modulus tests. The EMEs used by Colas in New Caledonia are manufactured from the same 20/30 South African asphalt imported in Bitu containers from Durban. The formulation studies were carried out in accordance with the European standards and with local aggregate (mostly basalt).

Several major projects using High Modulus Asphalt Mixes have been carried out in this territory, particularly:

- Construction of second carriageway of the Savexpress Highway:

This highway located in Nouméa, the administrative and economic capital of the country, is a major road for the territory. The pavement structure of standard Road Base Asphalt that was initially planned then received an alternative using High Modulus Asphalt, allowing for savings of 30 % on the total thickness.

- Koniambo Nickel treatment plant in the North of the country:

Colas took part in the construction of the roads of this vast industrial complex and proposed to the client the use of EMEs, particularly for the heavy-use roads (port platform and ore refining zone). The optimization of the pavement thicknesses through the use of higher performance materials reduced the work period by several weeks, which convinced the mining client to use this technique given the very tight time frames for this operation.

Picture 9: EME logistical platform at the Port of Koniambo

The search for a hard binder in Asian refineries is underway in order to have available in the Oceania zone an bitumen suitable for the manufacturing of High Modulus Asphalt Mixes.

3 Conclusion

EMEs constitute a modern, high-performance asphalt technique to address problems of increasing aggressivity of traffic while contributing to the concept of sustainable development. The reduction of thickness leads to savings on non-renewable resources, a reduction in excavation work in urban areas, and renovation of road shoulders.

The diversity of its road construction and industrial applications (docks, maneuvering areas) in the field of runways and taxiways for aircraft is another major strong point in its development.

The technique is thoroughly mastered, thanks to know-how and more than 20 years of experience. The technical assessment of the many projects carried out is highly satisfactory.

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5 Key words

High modulus asphalt, EME, Airport, Heavy structure, Pavement, Design method, Alize, Faarfield, Environmental impact