High Modulus Asphalt:
Assessment of Viability Based on Outcomes of Overseas Fact Finding Mission

By

T Distin (Sabita), L Sampson (Asphalt Academy), H Marais (Much Asphalt (Pty) Ltd) and B Verhaeghe (CSIR Built Environment)

INTRODUCTION

There is a perception that current South African flexible pavement design methodologies and (bituminous) pavement materials no longer are able to cope with the significant increases in traffic volumes and loads, particularly on heavily trafficked routes, and that they no longer offer road owners long-term, (virtually) maintenance-free solutions; the latter becoming increasingly more important so as to curb congestion and minimise road user costs. This notion may have been amplified by instances of poorly performing asphalt at challenging sites such as intersections where asphalt rutted prematurely. Also, the quest for higher rut resistance often led to asphalt being prone to moisture damage. Through studies conducted by the Gauteng Department of Public Transport, Roads and Works, it would seem that viable solutions have been found for these particular problems. Nevertheless, these perceptions may have led to a significant increase in the demand for cement concrete alternatives; the Gauteng Highways Improvement Project being but one example.

In 2006, Sabita identified the need to implement flexible pavement solutions that would meet the needs of road owners. One product identified by Sabita was *Enrobé à Module Élevé* (EME), or High-Modulus Asphalt (HiMA). It is a French technology that was conceived in the 1980s with the purpose of maximising stiffness and fatigue resistance, whilst ensuring that rutting and durability (particularly moisture resistance) requirements were still being met. It was initially intended to be used on the most heavily trafficked routes in France, as well as on airport pavements and container terminals, but early successes quickly opened up new avenues for its application. One of the fastest growing offsets of HiMA has been urban roads, based on the ability to reduce overall layer thickness as a result of the substantially higher stiffness of the material, while still being able to maintain the same level of performance. This has translated in direct savings in road construction material usage and construction costs.

Whilst Sabita foresaw the potential for implementing HiMA in South Africa, one of the initial constraints that had to be overcome was the capability of refineries to produce harder grades of binder as prescribed by the technology. The indications are that at least two local refineries can produce such a binder, which has brought us one step closer to the adoption of HiMA technology in South Africa, the remaining obstacles being: (a) the ability to integrate HiMA in the South African pavement design philosophy, (b) the ability to translate French mix design parameters into South African ones, (c) the ability of asphalt contactors to manufacture and pave the material, and (d) the ability to sell HiMA technology to major decision makers.

In order to better understand the HiMA concept and assess its viability for implementation in South Africa, the authors undertook a European study tour whereby they visited the French companies Colas, Total and Shell, as well as the Transport Research Laboratory (TRL) in the United Kingdom. TRL was appointed by the British Highway Authority to transfer and implement EME technology in the United Kingdom after the unsuccessful attempts by local practitioners. The authors are of the opinion that HiMA has great potential for implementation in South Africa, provided that the above constraints can be addressed effectively, and that it will be able to compete with concrete pavements to render a long-life pavement for heavily trafficked roads and airports. To this end, a fast-tracked technology transfer and implementation plan has been prepared (see Appendix A).

DEFINITION AND COMPOSITION OF HiMA

France has had a long track record of using bitumen-treated base (BTB) courses with 35/50 penetration grade bitumen. However, on account of the increases in traffic volumes and permissible axle loads (13 tons vis-à-vis our 9 tons), road designers had to find new ways for enhancing the structural strength and bearing capacity of pavement structures. This led to the introduction of harder penetration grade binders for use in BTB layers so as to increase the stiffness (modulus) of structural layers. However, to offset the risk of premature cracking associated with the use of these harder binder grades as well as risks of moisture damage, higher binder contents had to be used, which necessitated the use of finer gradings. This led to the development of *Enrobé à Module Élevé* (EME) or High-Modulus Asphalt (HiMA) in the 1980s by the French road administration, bitumen producers and road contractors.

In essence, HiMA is a hot-mix asphalt consisting of hard bitumen blended at a high binder content with good quality, fully crushed aggregate to produce a (relatively) fine-graded mix with a low air voids content. HiMA is designed to combine good mechanical performance with impermeability and durability. It is designed in the laboratory to yield high elastic stiffness, high permanent deformation resistance and high fatigue resistance, whilst also offering good moisture resistance and good workability.

The maximum stone sizes that can be used in HiMA are 10, 14 and 20 mm. A 0/14 continuously graded mix with a filler content of approximately 8 per cent is the most commonly used grading in France. The binder needs to conform to the European standard for hard binders, namely EN13924 (see Table 1). Most often, the 10/20 and 15/25 penetration grades used in HiMA are ready-to-use refinery-produced bitumens. In instances where refineries are unable to produce such binders, 35/50 penetration grade bitumens blended with organic additives such as gilsonite have been used successfully as an alternative. Modified binder could also be used, although this approach is seldom practiced. Although the use of the latter may enhance mechanical properties such as resistance to fatigue cracking and/or permanent deformation, the asphalt stiffness requirements may not always be met.

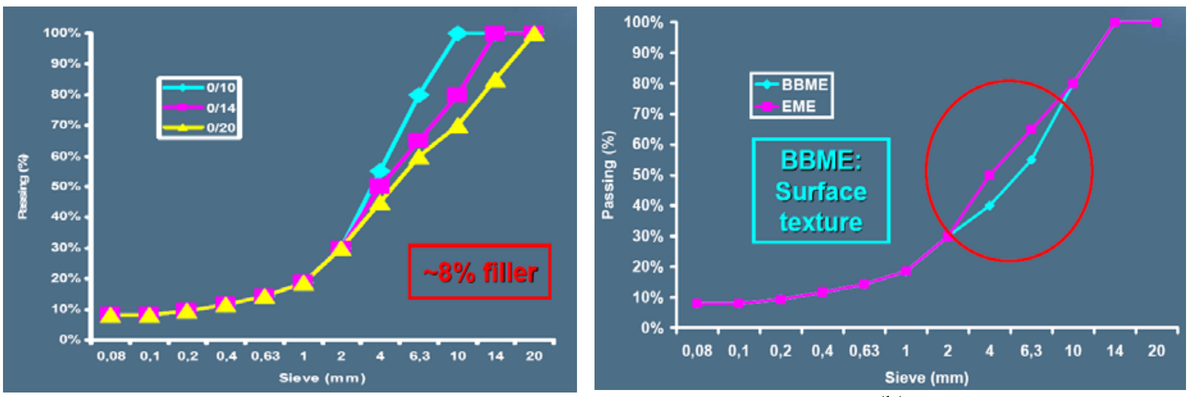
Two different types of HiMA are used in France: *Enrobé à Module Élevé* (EME) which is predominantly used as a base course, and *Béton Bitumineux à Module Élevé* (BBME) which is predominantly used as a binder course, and sometimes as a wearing course. In Europe, a binder course is defined as the layer on which the wearing course is placed. Its purpose is to resist and dissipate the high shear stresses close to the tyre. Therefore, a binder course needs to have a higher internal stability than a base course to resist these higher shear forces. Whereas EME can be made with 0/10, 0/14 or 0/20 gradings, BBME is restricted to either 0/10 or 0/14. Because BBME can also be used as a wearing course, its grading at the 4 mm and 6.3 mm is slightly coarser to allow for a surface texture with good skid resistance. Typical gradings for EME and BBME are shown in Figure 1.

Two classes of EME and three classes of BBME are defined: EME Class 2 and BBME Class 3 are specified for the most heavily trafficked roads. They require higher binder contents (approximately 6 per cent by mass of total aggregate), lower compacted voids, higher moisture resistance and higher rut resistance than the other EME and BBME classes.

TABLE 1: European standards for hard bitumen grades

Essential Requirement	Surrogate Characteristic	Test Methods	Unit	Classes				
				1	2	3	4	5
CONSISTENCY AT INTERMEDIATE SERVICE TEMPERATURE	Penetration at 25˚C	EN 1426	0,1 mm	-	TBR	15-25	10-20	-
CONSISTENCY AT ELEVATED SERVICE TEMPERATURE	Softening point	EN1427	˚C	-	TBR	55-71	58-78	60-76
	Viscosity at 60˚C minimum	EN 12596	Pa.s	NPD	TBR	550	700	-
DURABILITY (Resistance at 163 ˚C. EN 12607-1 or 3)	Change of mass, maximum		%	-	TBR	0,5	-	-
	Retained penetration, minimum	EN 1426	%	-	TBR	55	-	-
	Softening point after, minimum	EN 1427	˚C	-	TBR	Orig. Min. +2	-	-
	Increase in softening point, maximum	EN 1427	˚C	NPD	TBR	8	10	-
	Increase in softening point, maximum & Penetration Index before test (i.e. on original bitumen)	EN 1427	˚C Min Max	NPD	TBR	10 -1,5 +0,7	- - -	- - -
OTHER PROPERTIES	Viscosity at 135˚C, minimum	EN 12595	Mm2/s	NPD	TBR	600˚	700	-
	Fraass breaking point, maximum	EN 12593	˚C	NPD	TBR	0˚	3	-
	Flash point, minimum	EN 2592	˚C	-	TBR	235	245	-
	Solubility, minimum	EN 12592	% (m/m)	NPD	TBR	99,0	-	-

NPD: No Performance Determined (i.e) there are no regulations on the property)
TBR: Level or range To Be Reported by the supplier (i.e. declared values)



(a) (b)

FIGURE 1: Typical grading curves for (a) EME and (b) BBME (after TOTAL)

FRENCH MIX DESIGN METHODOLOGY

The French mix design method for HiMA is not different from that used for all their asphalt mixes, except that all tests are mandatory. It consists of 5 basic steps (see Figure 2):

- **Step 1: Selection of mix components**
  The selection of binder and aggregate should be in line with the demands of the specifications with an appropriate binder content estimated for the target grading. The binder content is controlled by a *Richness Modulus* (K), which is a function of the mass of the soluble binder expressed as a percentage of total dry mass of aggregate, the specific surface area of aggregate and the density of the aggregate. It is similar in concept to the calculation of binder film thickness in South Africa. The minimum Richness Moduli specified for EME and BBME mixes are given in Table 2.

- **Step 2 (Level 1 Design): Assessment of susceptibility to moisture damage and assessment of workability.**
  Assessment of susceptibility to moisture damage is done by means of the *Duriez* test. It consists of manufacturing specimens to a target void content (similar to the lowest permissible level of compaction in the field) using static compaction, and unconfined compression testing of two sets of samples of which one set was conditioned in water. If the ratio of the results after and before conditioning is above a certain value, the mix is deemed to be acceptable.
  Assessment of workability is done by means of *Gyratory Testing*, whereby the mix is subjected to a specified number of gyrations in the LCPC Gyratory Press Compactor. The tests are usually done at a temperature between 130° to 160°C depending on the viscosity of the binder. A 0.6 MPa vertical pressure is then applied on the top of the specimen. At the same time, the specimen is slanted slightly at an angle in the order of 1° (external) or 0.82° (internal) and submitted to circular movement. These various actions exert a compaction by means of kneading. The increase in compactness (i.e. via the decrease in percentage of voids) versus the number of revolutions is then recorded. If the voids close too rapidly, this is indicative of a potentially unstable mix. On the other hand, if the voids after having applied the specified number of gyrations are too high, this may be indicative of a mix that will be difficult to compact in the field, resulting in fairly high in situ voids, which ultimately may affect the durability of the mix. Whereas only maximum void limits are specified for EME, both minimum and maximum limits are specified for BBME (see Table 2).

- **Step 3 (Level 2 Design): Assessment of resistance to permanent deformation**
  The assessment of resistance to permanent deformation is carried out by means of a *wheel-tracking test* on slabs manufactured by rolling-wheel compaction. The mix is subjected to 30,000 uni-directional loads (frequency: 1 Hz, load: 5 kN, pressure: 0.6 MPa) at a test temperature of 60°C. The depth of deformation produced after each loading cycle is measured and plotted against the number of cycles. For HiMA, the test specifications call for a maximum rut percentage after 30,000 cycles on a 100 mm slab (see Table 2). This test is mandatory for BBME, but is not a key design parameter for EME.

- **Step 4 (Level 3 Design): Assessment of the elastic stiffness**
  The asphalt mix stiffness is determined by either a complex modulus test (sinusoidal loading on a trapezoidal or parallelepiped specimen) or a uni-axial tensile test (on a cylindrical or parallelepiped specimen). Small deformations are induced in a sample through controlling time or frequency, temperature and loading. The modulus (stress-strain ratio) is computed for each basic test. Using time-temperature transposition, an elastic stiffness master curve is then developed. Characterisation of the elastic stiffness of HiMA is a mandatory test. The minimum specifications for elastic stiffness are

set for a test temperature of 15°C using a test frequency of 10 Hz and a loading time of 0.02 seconds (see Table 2).

- **Step 5 (Level 4 Design): Determination of fatigue life**
  Fatigue testing is done on trapezoidal specimens in constant displacement mode. The tests are conducted at a temperature of 10°C using a loading frequency of 25 Hz. After 1 million load repetitions, the tensile strains measured on the specimen should exceed the minimum specified values in Table 2 in order for the mix to be acceptable. This is also a mandatory test for HiMA.

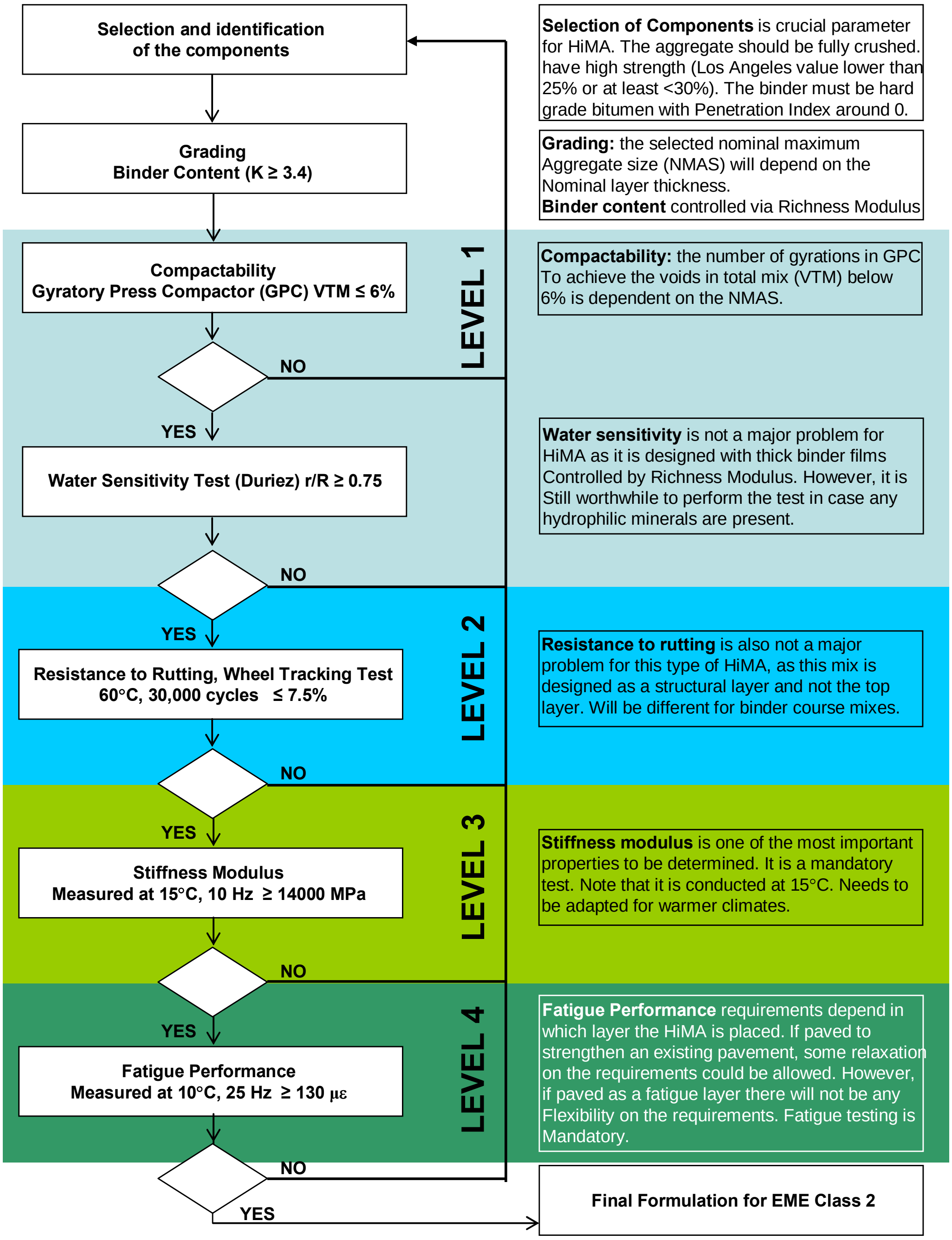


FIGURE 2: Example of the EME Class 2 design process (after SHELL)

TABLE 2: Minimum Characteristics of HiMA according to French Standards
(HiMA Classes best suited for conditions in South Africa are marked in yellow)

Performance	EME NFP98-140		BBME NFP98-141		
	EME Class 1	**EME Class 2**	**BBME Class 1**	**BBME Class 2**	**BBME Class 3**
Richness Modulus	≥ 2.5	≥ 3.4	≥ 3.5 for 0/10 and ≥ 3.3 for 0/14		
% voids with the Gyratory compactor	≤ 10	≤ 6	5 to 10% for 0/10 and 4 to 9% for 0/14		
Duriez test, r/R	≥ 0.70	≥ 0.75	≥ 0.80		
Rutting test: 30,000 cycles at 60°C (*)	≤ 7.5%		≤ 10%	≤ 7.5%	≤ 5%
Complex modulus at 15°C (MPa)	≥ 14,000		≥ 9,000	≥ 12,000	
Fatigue test in µdef at 1 million cycles, 10°C and 25 Hz	≥ 100	≥ 130	≥ 110	≥ 100	
(*) Rutting resistance not the key parameter for base course layer					

PAVEMENT DESIGN

Since the 1970s, France has seen a shift towards the use of higher binder contents in structural layers, combined with the use of higher viscosity binders, resulting in increased elastic stiffness. This is illustrated in Figure 3. This evolution has culminated in the development of a series of well-defined high modulus asphalt mixes which offer good load-spreading ability, good fatigue resistance, good resistance to permanent deformation and good resistance to moisture damage, which are the four key parameters for long-life pavements. The better load-spreading ability and fatigue resistance of HiMA result in pavement structures that are less sensitive to loading since, for the same thickness, they can accommodate higher tensile strains at the bottom of the layer compared to conventional base courses. They also reduce vertical strains on the subgrade as well as stresses in the granular layers. Whereas the above will result in longer life pavements, the practice in France has been to reduce layer thicknesses so as to conserve material usage. The use of HiMA has enabled asphalt layer thicknesses to be reduced by between 25 and 35 per cent.

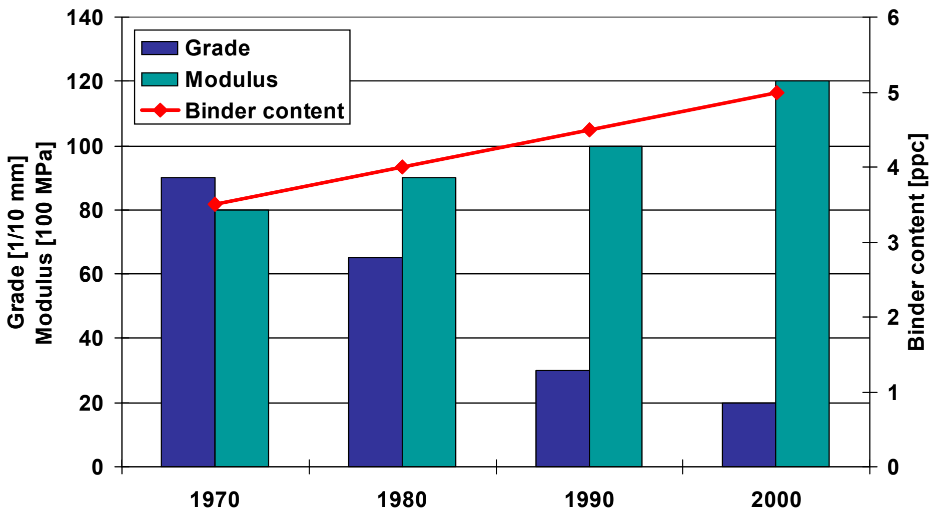


FIGURE 3: Evolution of base course mixes in France (after COLAS)

The average and minimum specified layer thicknesses of HiMA are stipulated in Table 3. Since HiMA is a structural layer, it is critical that the specified layer thicknesses are met during construction. It should be noted that the average layer thicknesses of HiMA are generally lower than those of bitumen-treated base courses (BTBs) or large-aggregate mixes for bases (LAMBs). The reason for this is that HiMA, apart from its higher stiffness, is also richer in binder which renders the mix more resistant to fatigue cracking. Another attribute of HiMA is that the mix is virtually impermeable, which enables HiMA to be surfaced with a thin or ultra-thin asphalt mix.

TABLE 3: Average and minimum HiMA thicknesses

Type of Grading	Average thickness (mm)	Minimum thickness (mm)
0/10	60 to 80 (EME) 50 to 70 (BBME)	50
0/14	70 to 130 (EME) 60 to 90 (BBME)	60
0/20	90 to 150 (EME)	80

TRL performed accelerated pavement tests on pavements with EME Class 2 binder courses with 15/25 penetration grade bitumen in the UK with the purpose of comparing its performance with that of a conventional High Density Macadam (HDM) or Dense Bitumen Macadam (DBM) binder course. On completion of the testing, it was concluded that (TRL, 2005):

1. Compared to conventional HDM, EME Class 2 was deformation resistant, and its high binder content helped to ensure that it was durable and impermeable to water. Furthermore, its load spreading ability was superior to HDM. These attributes make it an ideal component in the construction and maintenance of durable modern, high performance heavily trafficked flexible pavements.
2. In new pavements, construction thicknesses can be maintained with more assurance of achieving the same structural life as that of a pavement constructed using HDM. The thick binder film and impermeability of EME will also help ensure that the pavement is waterproof and at less risk of any problems caused by the ingress of water.
3. The trials have demonstrated that a full lane inlay or a longitudinal trench inlay of EME binder course covered by a thin surfacing is an effective maintenance treatment to remedy surface rutting or cracking in long-life pavements. The richer material with a finer grading makes it more user-friendly and the trials have demonstrated that excellent compaction can be achieved adjacent to a longitudinal joint.
4. Analytical pavement design indicates that the use of EME Class 2 material could result in the bound layer thicknesses being reduced by around 25 mm for a predicted life of 80 million single axle loads compared with HDM.

A similar study was conducted by *Service Technique des Bases Aeriennes* (STBA) with the objective of determining the structural number (SN) of HiMA for use in the structural design of airport pavements. The results indicated that the SN for BBME Class 1 is 2.5, whereas that for EME Class 2 is 1.9. When these SNs are compared with those for granular base courses (SN=1), emulsion-treated base courses (SN=1.2) and bitumen-treated base courses (SN=1.5), it was concluded from the study that HiMA would be ideally suited for application on airports as a replacement layer or overlay, or as a thinner structural layer when used in new construction.

APPLICATION OF HIGH-MODULUS ASPHALT

HiMA offers good resistance to rutting and, on account of its load-spreading ability, is being used successfully as a base course and/or binder course layer. It is used in new construction as well as rehabilitation, whilst the ability to reduce layer thicknesses makes HiMA also ideally suited for application in urban areas. More particularly, HiMA is used:

- On heavily trafficked routes, particularly where traffic is slow and channelised, such as on major bus routes;
- In specific pavements subjected to heavy loads such as dedicated truck routes, loading bays and container terminals;
- In constrained (boxed-in) pavements such as those found in urban and peri-urban areas;
- On new pavements as a base course layer;
- In rehabilitation, where between 80 and 120 mm is milled off and replaced with HiMA, often surfaced with a very thin asphalt wearing course;
- On runways and taxiways on airports – EME Class 2 is regularly used on French airports.

EME Class 2 and BBTM Class 3, combined with a very thin asphalt wearing course (20-30 mm), are becoming the most popular rehabilitation methods used in France with some two million tons being placed annually as it combines structural strength and durability with the provision of adequate skid resistance.

The main aspects that need to be considered during construction are:

- Ensuring that there is good bonding between subsequent layers (the application of a tack coat is essential);
- Ensuring that HiMA meets all specifications, including grading, binder type and binder content;
- Ensuring that the mixing temperature is between 160 and 180°C and that the compaction temperature never drops below 145°C;
- Ensuring that the support layer is sufficiently stiff so as to enable HiMA to be compacted to the required density;
- Ensuring that the average thicknesses are met, and particularly the minimum thicknesses;
- Ensuring that HiMA is protected from significant day/night temperature variations, which could cause thermal cracking, by the application of an overlay of adequate thickness.

VIABILITY FOR SOUTH AFRICA

As was pointed out in the introduction, the main obstacles to the successful transfer and implementation of HiMA in South Africa are: (a) the ability to manufacture harder grades of binder in South Africa; (b) integrate HiMA in the South African pavement design philosophy, (c) the ability to translate French mix design parameters into South African ones, (d) the ability of asphalt contactors to manufacture and pave the material, and (e) the ability to market HiMA technology to major decision makers.

Ability to manufacture harder grades of bitumen in South Africa:

Harder grades of bitumen produced by two local refineries were sent over to France for testing. The feedback was positive: both binders had properties which satisfied the 15/25 penetration grade specifications (Class 3 in Table 2). Hence, at least two refineries seem to be able to produce binders that would meet the specifications for HiMA. If some of the refineries were to be unable to produce 15/25 penetration grade bitumen, they could modify 40/50 penetration grade bitumen by the addition of organic additives, or consider polymer modification of the base bitumen.

Integration of HiMA in the South African pavement design philosophy:
Although the structural design approaches of France and the UK are distinctly different from those used in South Africa (e.g. deep strength asphalt versus high-quality crushed stone base course layers), the integration of HiMA in the South African flexible pavement design method does not seem to be insurmountable. Even though there are no off-the-shelf transfer functions available for HiMA that could be incorporated in the South African mechanistic design method, fatigue of HiMA should not be a design concern on account of its higher binder content, particularly if the tensile strains at the bottom of the layer can be kept under control. Preliminary structural analyses performed on typical South African pavements have shown that:

- Compared to an HMA layer of similar thickness (70mm) placed on a G1 base course, the high vertical stresses in the pavement with HiMA tend to be confined to the HiMA layer, whereas in the case of conventional pavement, higher vertical stresses are transferred to the granular layer. The structural life of the pavement with the HiMA layer is increased by at least 250% compared to the benchmark;
- Compared to a 50mm HMA placed on top of a 180mm BTB on a C3 subbase, a 100mm HiMA on the same subbase resulted in a similar life, despite a reduction of 130mm in pavement thickness;
- A 50mm HMA placed on a 150mm G1 (also on a C3 subbase) gave a similar life to that of a 70mm HiMA placed on the same subbase.

Translation of French mix design parameters:
As for structural design, adaptation of French testing procedures and design parameters is feasible. Figure 4 illustrates the South African equivalent of the French testing procedures. The challenge, however, is to translate the French specifications, which intrinsically are linked to their particular testing procedures, into their South African equivalents. One avenue is to learn from the experience of TRL. Another avenue, which is preferred, is to conduct parallel testing between South Africa and France. Two French companies, namely Shell and Colas, are currently in the process of designing HiMA using South African binders and aggregates based on French standards. If they are successful, and all indications are that they will be, duplicate testing will be done in South Africa using South African mix design procedures. It is expected that equivalent South African specifications can be derived from this exercise.

Ability of asphalt contactors to manufacture and pave HiMA:
The manufacturing process of HiMA is not different from that of normal asphalt with the exception that HiMA is mixed at higher temperatures to ensure proper coating of the aggregate with the viscous binder. Dedicated bitumen tanks will be required as the binder will have to be heated to higher temperatures prior to mixing (similar to polymer-modified binder and bitumen-rubber).

As mentioned previously, the paving temperature of the asphalt should not be less than 145°C when the asphalt exits the paver to ensure that the required compaction is achieved. When the technology was initially transferred to the United Kingdom, they expected to struggle with achieving the required compaction and were told that very heavy (45 tons) pneumatic tired rollers would be required. Subsequently, it has been found that 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 so as to ensure that longitudinal cracks do not appear. The target field voids should be between 4 and 6 per cent, which relates to a density of between 94 and 96 per cent of maximum theoretical relative density (MTRD).

Due to the high binder content and fine grading of EME Classes 1 and 2, the surface finish after construction is very smooth and shiny. It is therefore not ideal to have traffic on the layer as it could pose a safety risk as a consequence of poor skid resistance. Where traffic accommodation is expected to be a problem, the application of the surfacing layer shortly after construction of the HiMA layer is recommended.

Ability to market HiMA technology to major decision makers:
The key to HiMA technology becoming an accepted practice in South Africa is that we would need to be able to convince road authorities foremost that it would be more cost effective to use HiMA than local conventional pavement materials types and structures. Whilst the Europeans portray the reduction in layer thicknesses vis-à-vis conventional HMA as one of the main benefits of HiMA, our philosophy in SA should rather be that it is a material that can render longer pavement life with improved performance over using conventional crushed stone bases with asphalt wearing courses.

The key benefit of a longer life pavement is that inter alia it can ensure improved whole life cycle costing with reduced user delays on our heavily trafficked roads. In order to demonstrate this benefit we would need to construct a trial section with HiMA as a base layer surfaced with a thin asphalt wearing course and subject it to accelerated pavement testing (APT). The results obtained from the performance of this pavement structure and materials can be compared with historical data of conventional pavement materials and structures. This information would then become the premise on which we substantiate our stated philosophy and be used as a credible source to convince clients and their engineers that HiMA should be the premium material of first choice for constructing and rehabilitation heavily trafficked pavements for freeways and airports into the future.

It will also be important to stress to local pavement engineers that this is not a research project but the transfer of appropriate technology to suit local environmental conditions and pavement engineering needs in Southern Africa.

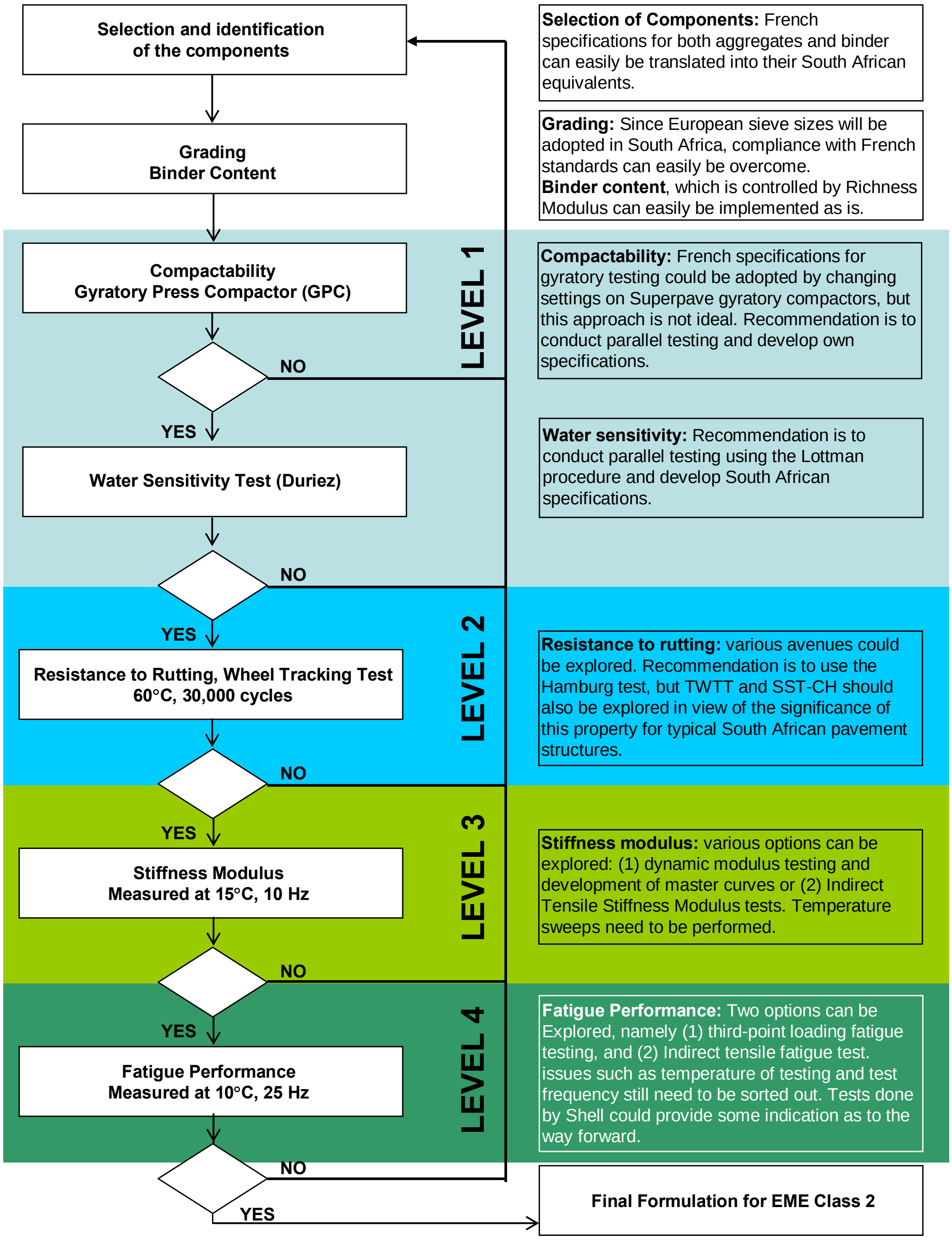


FIGURE 4: South African tests that potentially could replace French testing procedures