TRANSFER OF HIGH MODULUS ASPHALT TECHNOLOGY TO SOUTH AFRICA

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Abstract

This paper presents the development of an interim guideline for the design of High Modulus Asphalt (HiMA) for bases. The procedure for the development of a trial blend is discussed, including the selection criteria for aggregates and binder and the choice of a grading curve. Like the original French method, the HiMA design guideline is performance orientated. Trial mixes are assessed based on the workability, durability, elastic modulus, resistance against permanent deformation and fatigue performance of the mix. Local criteria for these performance indicators were set by comparing the performance of a mix design against European and South African test methods. Structural analysis has shown that the use of HiMA may decrease the required base layer thickness by 30 percent. Damage models for the prediction of the rutting and fatigue performance are currently under development as part of the revision of the South African pavement design method. The guideline presented in the paper represents a complete method for the design of HiMA mixes using local test equipment. The guideline however, requires validation through accelerated pavement testing and field trials before it can be used with confidence by industry.

1. INTRODUCTION

South Africa's continued economic growth has seen large increases in volumes of heavy vehicles on the country's road network. To ensure long-term serviceability of our roads, and to underpin low-intervention strategies and sustainable practise, asphalt mix design technology has to keep pace with the higher demands placed on pavements. One of the initiatives aimed at increasing the options available for the design of heavy trafficked sections is the High Modulus Asphalt (HiMA) Technology Transfer (T^2) project funded by the Southern African Bitumen Association (Sabita).

The HiMA, or Enrobés à Module Elevé (EME), technology was developed in France in the early 1990's where it is currently used extensively on main routes, airports as well as urban roads. HiMA combines superior permanent deformation resistance with high structural stiffness and good fatigue performance. The key characteristics of HiMA are a high binder content of hard bitumen with a penetration value of between 10 and 25 combined with good quality, fully crushed aggregate.

The objective of this paper is to present the methodology followed in the development of local interim guidelines for the design of HiMA mixes and the design of pavement structures containing HiMA layers (Denneman et al, 2010). The scope of the paper is limited to HiMA mixes used as base layers, which is expected to become the primary application of the technology in South Africa. The use of HiMA for surfacing layers is not discussed in the paper.

The mix design procedure is discussed in Section 2 of the paper. Section 3 presents the methodology followed in the laboratory study. The results of the experimental work were used in the development of local performance criteria for HiMA. Finally some examples of structural designs including HiMA layers are discussed.

2. HIMA MIX DESIGN

The design process in the interim guideline is similar to the procedure for the design of HiMA described in the LCPC bituminous mixtures design guideline by Delorme et al (2007). The steps of the process are described in this section. This section further includes the criteria for the selection aggregates, which were set based on local experience with the design of hot-mix asphalt. The guidelines for the development of grading curves are based on the work by Delorme et al (2007). For the binder specifications, the European standards were maintained.

2.1 Design Process

The French method for HiMA design involves the use of so called performance specifications. The aim of performance specifications is to evaluate mix properties in relation to the loading and environmental conditions to which the material will be subjected to in the field. The intention of these specifications is to prescribe the performance of the final product, without necessarily putting limitations on the composition of the material. An advantage of this approach is that it reduces barriers to innovation and promotes the efficient use of natural resources, without sacrificing performance. Figure 1 shows the HiMA mix design process.

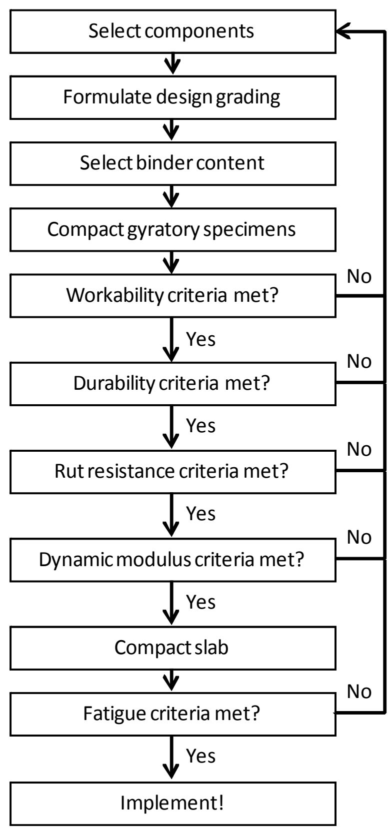

Figure 1: Mix design process

The first step is to select appropriate mix components in terms of aggregate and binder. A suitable grading is developed from the different aggregate fractions. The binder content is set based on a minimum richness factor, similar to the film thickness used in South Africa. Using this trial mix design gyratory specimens are compacted. In the test a maximum air void content after a set number of gyrations has to be achieved. This is the first of the performance criteria, aimed at creating a workable mix. If the workability criteria is met specimens are tested subjected to a durability test. The remaining performance criteria relate to a minimum dynamic modulus requirement, a minimum level of resistance to permanent deformation and finally a minimum fatigue life.

2.2 Aggregate selection

In France, HiMA is typically produced using fully crushed fractured aggregate. In the selection of an aggregate source, both angularity and surface texture are important. High aggregate angularity and sufficient surface texture assist in the creation of voids in the mineral aggregate (VMA). The VMA has to be such that it can accommodate a fairly high binder content. The aggregate selection guidelines proposed in the interim design guide are shown in Table 1. The criteria are similar to those recommended for HMA as contained in Taute et al. (2001). The particle index test provides a measure of aggregate angularity and surface texture. The value for particle index is tentative. Generally aggregates with a high particle index result in a higher VMA. The flakiness index for HiMA aggregate should preferably lie between 10 and 15 (Delorme, 2007). Note that if the material is to be used in a surfacing layer a minimum Polished Stone Value (PSV) will also be required to insure skid resistance.

Table 1: Aggregate selection criteria

Property	Test	Method	Criteria
Hardness	Fines aggregate crushing test: 10 %FACT	TMH1, B1	≥ 160 kN
	Aggregate crushing value ACV	TMH1, B1	≤ 25%
Particle shape & texture	Flakiness Index test	SANS 3001	≤ 25
	Particle index test	ASTM D3398	>15
Water absorption	Water absorption coarse aggregate (>4.75mm)	TMH1, B14	≤ 1.0 %
	Water absorption fine aggregate	TMH1, B14	≤ 1.5 %
Cleanliness	Sand equivalency test	TMH1, B19	≥ 50

2.3 Developing a grading curve

The LPC bituminous mixtures design guide provides target grading curves and envelopes for HiMA mixes (Delorme et al, 2007). It should be noted that these only provide a point of departure for the mix design process and that they should not be used to impose restrictions on the grading in the fashion of the current South African COLTO specifications. The literature survey performed as part of this study found that grading envelopes provided by Delorme et al. (2007) of the Laboratoire Central des Ponts et Chaussées (LCPC) are different from those contained in the report that deals with the implementation of HiMA in the United Kingdom, produced by the Transport Research Laboratory (TRL) (Sanders & Nunn, 2005). Until more experience is gained in South Africa, it is recommended that the envelopes published in the LPC guideline be used.

The French guideline for grading curves cannot readily be translated into general South African practice. This is due to the definition of the maximum particle size and the use of European sieve sizes. In South Africa (SA), the nominal maximum particle size (NMPS) is defined as one sieve size larger than the first sieve to retain at least 10% of aggregate. The French use the maximum stone size *D*, with the requirement that 100 % of aggregate passes the sieve at 2*D*, 98-100% passes at 1.4 *D* and 85-98% passes at *D*. In this paper, the French definition of maximum aggregate size is used. The grading guidelines for HiMA base courses are shown in Table 2 for both European and South African standard sieve sizes. The percentage passing values for the South African standard sieve sizes were determined by interpolating the data for the European sieves. For key sieve sizes, the table provides a target grading that can be used as a point of departure, and also proposes typical grading envelopes.

Table 2: Target grading curves and envelopes for HiMA base course

Percent passing sieve size	*D* = 10 mm			*D* = 14 mm			*D* = 20 mm		
	min.	target	max.	min.	target	max.	min.	target	max.
6.7 mm	47	56	68	52	54	72	46	54	66
6.3 mm	45	55	65	50	53	70	45	53	65
4.75 mm		53		43	49	63	42	49	62
4.0 mm		52		40	47	60	40	47	60
2.36 mm	32	36	44	28	36	42	28	36	42
2.0 mm	28	33	38	25	33	38	25	33	38
0.075 mm	6.4	6.9	7.4	5.5	6.9	7.9	5.5	6.7	7.9
0.063 mm	6.3	6.7	7.2	5.4	6.7	7.7	5.4	6.7	7.7

2.4 Binder selection and the richness factor

In Europe, either a 10/20 or a 15/25 Pen grade binder, conforming to EN 13924, is typically used in HiMA mixes. However, the only binder available locally for use in the technology transfer project to date has been a 20/30 Pen grade conforming to EN 12591. 15/25 penetration grade bitumen is expected to become available in South Africa in the near future. A summary of EN requirements for hard binders are shown in Table 3.

Table 3: Summary 10/20, 15/25 and 20/30 binder specifications (EN 13924 and EN 12591)

Property	Test method	Unit	Penetration grade		
			10/20	15/25	20/30
Before RTFOT					
Penetration at 25 °C	EN 1426	0.1 mm	10-20	15-25	20-30
Softening point	EN 1427	°C	58-78	55-71	55-63
Viscosity at 60°C	EN12596	Pa.s	>700	>550	>440
After RTFOT					
Increase in softening point	EN 1427	°C	< 10	< 8	< 8
Retained penetration	EN 1426	%	-	> 55	> 55
Mass change		%		< 0.5	< 0.5

Table 4 shows the minimum binder contents (P_b) for different HiMA base material classes and aggregate densities (ρ). P_b is expressed as the percentage of binder by mass of total mix. The French specifications include two classes of HiMA mixes for bases: Class 1 for 'light' traffic, and Class 2 for heavy traffic. The mix designs tested in South Africa were of Class 2 specification. The values in the table are intended as a point of departure for the selection of optimum binder content.

Table 4: Typical values for minimum binder content and target richness modulus

	HiMA base course		
	Class 1	Class 2	
D (mm)	10,14,20	10,14	20
$P_{b\ min}$ ρ= 2.65 g/cm3	3.8	5.1	5.0
$P_{b\ min}$ ρ= 2.75 g/cm3	3.8	4.9	4.9
Richness modulus *K*	2.5	3.4	3.4

The richness modulus *K* also shown in Table 4, is a proportional value related to the thickness of the binder film coating the aggregate. It is akin to the film thickness calculation in the South African TRH 8. The richness modulus *K* is a key design parameter used in the French asphalt mix design method. The values in Table 8 should be adhered to. *K* is obtained from:

$$TL_{est} = K \cdot \alpha \sqrt[5]{\Sigma} \quad (1)$$

Where:

TL_{est}: is the binder content by mass of total aggregate. TL_{est} can be converted to the binder content by mass of total mix (P_b) generally used in South Africa using Equation 2

$$TL_{est} = \frac{100 P_b}{(100 - P_b)} \quad (2)$$

α: is a correction coefficient for the relative density of the aggregate (RDA)

$$\alpha = \frac{2.65}{RDA}$$

Σ: is the specific surface area calculated from: $100\Sigma = 0.25G + 2.3S + 12s + 150f$

Where:

G: is the proportion of aggregate retained on and above the 6.3 mm sieve,

S: is the proportion of aggregate retained between the 0.25 mm and 6.3 mm sieves,

s: is the proportion of aggregate retained between the 0.063 mm and 0.25 mm sieves,

f: is the percentage passing the 0.063 mm sieve

3. EXPERIMENTS TO DEVELOP LOCAL PERFORMANCE SPECIFICATIONS

An extensive laboratory study was conducted to translate the French performance specifications for HiMA to South African equivalents. To achieve this, a mix was designed by a laboratory in France using South African mix components. The mix was subjected to the relevant French performance tests. Subsequently, the mix was replicated at the CSIR laboratory and evaluated using local test methods for the various performance parameters. The results were used to compare the relative performance of the mix for French and South African test methods. The set of performance tests used in the French mix design procedure and the selected locally available equivalents are shown in Table 5.

Table 5: French performance tests and selected South African equivalents

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 Tester
Dynamic modulus	EN 12697-26: Flexural beam	AASHTO TP 62 dynamic modulus
Fatigue test	EN 12697-24: Prism	AASHTO T 321 Beam fatigue

3.1 Materials

The binder used for the T^2 project was a 20/30 PEN in accordance with the specifications shown in Table 3. Various grading curves were developed during the project, all falling within the recommended grading envelope shown in Table 2. Improvements on the initial mix design prepared at the French laboratory were made by using alternative aggregate sources. The Dolorite aggregate of the intial mix was replaced by Quartzite and Granite in later mix designs. Increased fatigue performance was achieved by increasing the binder content. The increase in binder content was made possible through the selection of aggregates that allowed higher Voids in Mineral Aggregate (VMA).

3.2 Sample preparation

The mixing temperature for the binder was determined using the method in TMH1 C2. The aggregates and binder were prepared in accordance with the protocols in TMH1. After mixing the loose material was conditioned using a method known as “short term aging”. The aim is to simulate the aging that takes place during the production of the mix at the plant and transport to site. The procedures are described by Von Quintus et al (1991) and Bell et al (1994). Short term aging conditioning is achieved by aging the loose mix in an oven at compaction temperature for four hours before compaction.

Gyratory compacted specimens were prepared for the workability, dynamic modulus and durability tests. Slabs were compacted, from which specimens were cut for use in the permanent deformation and fatigue tests. The specimens were compacted to an air void content of approximately 5%. The French design guideline states that tests should be performed on specimens with an air void content of between 3% and 6%.

3.3 Workability (gyratory compactor study)

The first performance criterion for HiMA pertains to the workability of the mix. Workability is assessed by monitoring the effort required to compact the material in the European gyratory compactor (EN-12697-1). Specifications are set for the maximum air void content after 100 gyrations, to ensure that the desired density can be readily achieved under the rollers in the field. The gyratory compactors available in South Africa are of the American SUPERPAVE (ASTM D6926) configuration. The ASTM D6926 and EN-12697-1 standards both prescribe a rate of 30 gyrations per minute and a compaction pressure of 600 kPa. The angle of gyration however differs, where the first uses an angle of 1.25° the latter requires 0.82°. The angle of gyration is shown schematically in Figure 2.

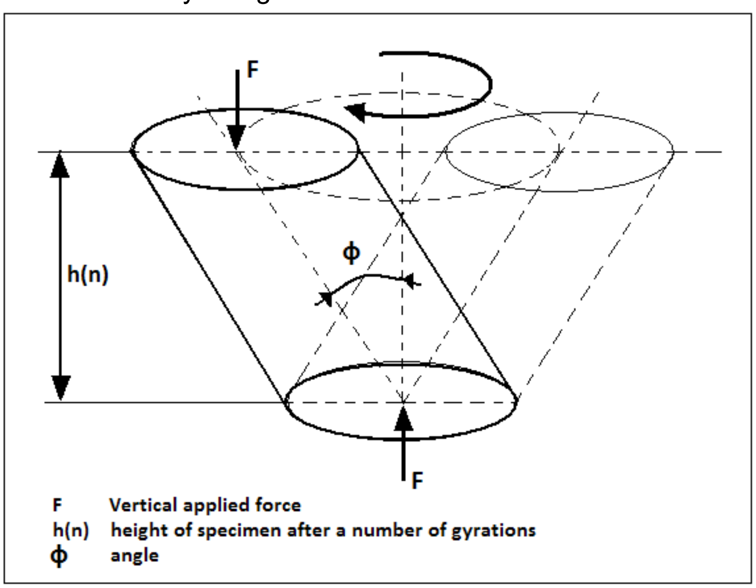

Figure 2: Configuration of a gyratory specimen during compaction

The larger gyration angle of the SUPERPAVE compactors results in a significantly higher rate of compaction. A comparative study was conducted to convert the French workability criteria to equivalent criteria using the SUPERPAVE gyratory compactor. The IPC Servopac gyratory compactor in the CSIR laboratory has an adjustable angle of gyration and the study could therefore be executed using a single compactor. Compaction trials were performed on two HiMA mix designs. In excess of five specimens were compacted for each mix using both of the compaction angles. Figure 3 shows the average compaction curves obtained for the two mixes. The graph shows that for the HiMA mixes under study a compactive effort of 100 cycles using the European gyratory angle corresponds to approximately 45 cycles in a compactor set to SUPERPAVE specifications. The of the compaction study are summarized in Table 6. Based on the results it was proposed set an indicative maximum air void criteria at a compactive effort of 45 SUPERPAVE gyrations for South African HiMA mixes

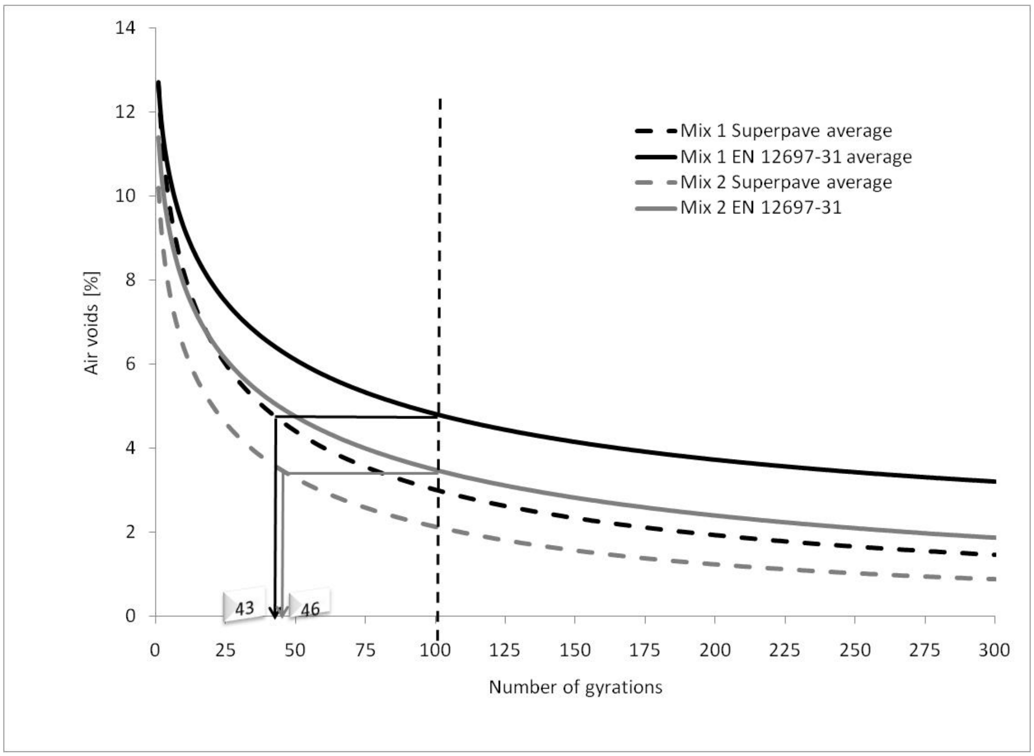

Figure 3: Gyratory compaction curves for two mixes using European and SUPERPAVE configuration

Table 6: Summary of gyratory compaction study

HiMA Mix design	**1**		**2**	
Specification	**EN 12697-31**	**SUPERPAVE**	**EN 12697-31**	**SUPERPAVE**
Number of specimens	9	8	5	5
Average voids [%] after 100 gyrations	4.8	3.0	3.5	2.2
Standard deviation	0.8	0.9	0.8	0.4
Coefficient of variation [%]	16.0	30.0	22.1	19.8
Equivalent gyrations	100	43	100	46

3.2 Durability

The durability of HiMA is assessed in France using an unconfined compressive test (EN 12697-12) on moisture conditioned specimens (Duriez test). In South Africa, the modified Lotmann test in accordance with ASTM D4867 is generally used for this purpose. Local performance criteria in terms of the ratio between original and indirect tensile strength (ITS) are available for HMA (Taute et al, 2001). It was deemed unnecessary to develop separate durability criteria for HiMA, instead the existing values for HMA, as shown in Table 7, were maintained.

Table 7: Minimum TSR criteria after (Taute, Verhaeghe, & Visser, 2001)

Climate	Permeability		
	Low	Medium	High
Dry	0.60	0.65	0.70
Medium	0.65	0.70	0.75
Wet	0.70	0.75	0.80

3.3 Permanent deformation

The resistance against permanent deformation (rutting) of the HiMA is assessed in France by means of wheel tracking tests on slabs in accordance with EN 12697-22. The Repeated Simple Shear Test at Constant Height (RSST-CH) was selected as a locally available test method. This method was selected, because it is the standard test used in the effort to revise the South African Pavement Design Method currently underway. The test is performed in accordance with the AASHTO 320-03 protocol with certain alterations and improvement to better suit the requirements of the SAPDM project (Denneman, 2009, Anochie-Boateng et al, 2010). The intention is to develop an additional set of deformation criteria for wheel tracker type tests at a later stage.

In the RSST-CH (performed to standard protocol) a horizontal shear force of 69 kPa is applied to the cylindrical specimen. The load is applied for 0.1 second followed by a 0.6 second rest period. The horizontal deformation is measured over height of the specimen during the test. The rate at which permanent shear strain accumulates in the material during the test has been used to predict deformation in the field. RSST-CH permanent deformation tests were performed at three different temperatures. Tests are run up to 5 000 repetitions or 5 % permanent strain, whichever is reached first.

The average permanent deformation response for the HiMA mix designed by the French laboratory is shown in Figure 4. The figure also shows the results for a bituminous base material (BTB) with a 40/50 Pen grade binder tested as part of the SAPDM project. The results indicate that HiMA potentially has a much improved resistance against permanent deformation compared to BTB. The permanent deformation performance of the HiMA mix was tested in accordance with EN 12697-22 in France. The comparative performance of the mix in the European wheel tracking test and the in the RSST-CH was used to set tentative performance criteria for use in South Africa.

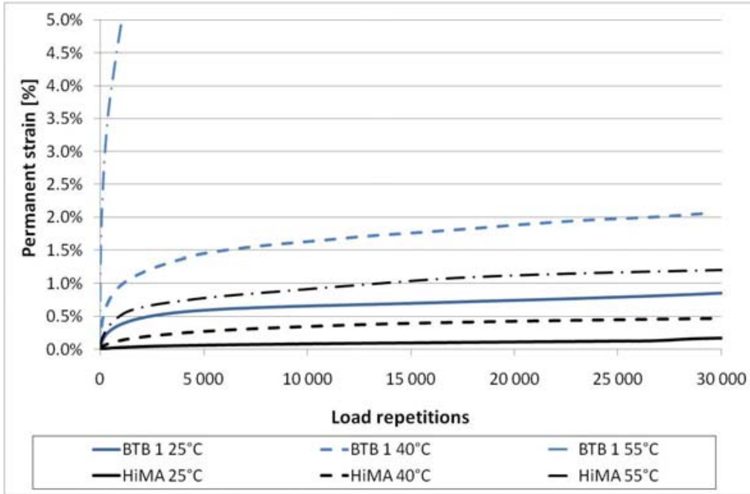

Figure 4: Permanent deformation HiMA compared to BTB

3.4 Dynamic modulus

Another performance requirement for HiMA mixes pertains to the dynamic modulus of the mix. The minimum modulus for a HiMA base course material is 14 GPa at a temperature of 15°C and a loading frequency of 10 Hz. The dynamic modulus of the material was determined using the AASHTO TP 62 dynamic modulus protocol, which also forms an integral part of the revision of the SAPDM (Anochie-Boateng et al, 2010). Apart from determining the dynamic modulus at a set loading time and temperature, the equipment can be used to perform frequency and temperature sweeps on the material. The results of these sweeps allows the construction of a master curve, which in turn can be used to calculate the dynamic modulus of the material for any combination of temperature and load frequency. Figure 5 shows the construction of a mastercurve for the HiMA material. Frequency sweep tests are performed at a range of temperatures as shown in Figure 5a. The modulus results at the different temperatures are shifted to form a continuous curve using the shift factors shown in Figure 5b. The mastercurve thus developed for the HiMA indicates that the mix is relatively stiff compared to other mix types at high temperatures (and low frequencies), while it has a similar stiffness at low temperatures (and high frequencies). These characteristics of the mastercurve are related to the high resistance against permanent deformation in combination with good fatigue performance exhibited by HiMA mixes. The French performance criteria of 14 GPa at 10 Hz and 15°C was maintained in the South African interim design guideline.

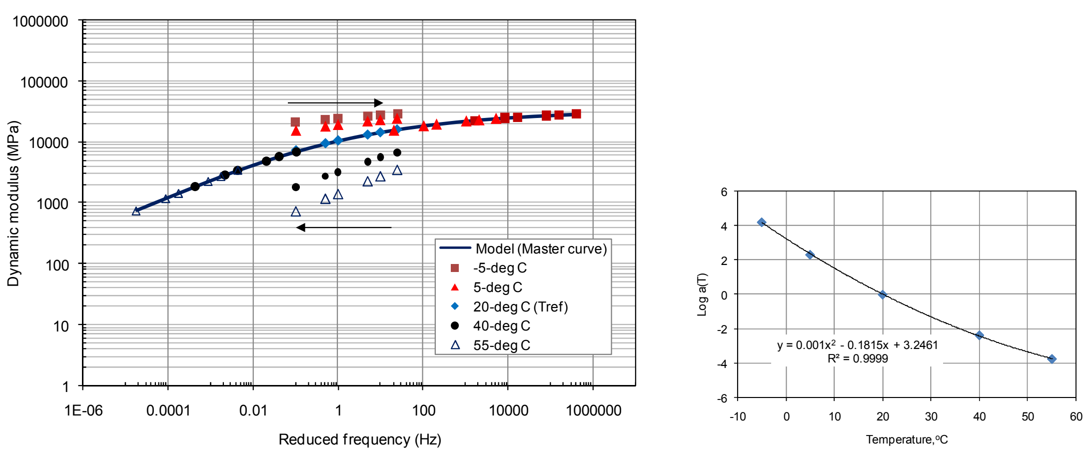

Figure 5a: Construction of a master curve for HiMA mix, b: Shift factors

3.5 Fatigue

The final performance to be met by a HiMA mix design is a minimum number of repetitions in a standard fatigue test. In the French design method tests are performed on trapezoidal specimens. In South Africa, a four point bending (FPB) fatigue test on beam specimens is typically used. Fatigue tests were performed in accordance with the protocols developed for the SAPDM project as discussed in Anochie-Boateng et al (2010). The fatigue results for the HiMA mix in terms of number of repetitions to failure at different strain levels are shown in Figure 6. The relative performance of the French mix design subjected to trapezoidal and the FPB testing was compared. Based on the comparison, minimum specifications were set for the performance of HiMA in FPB tests.

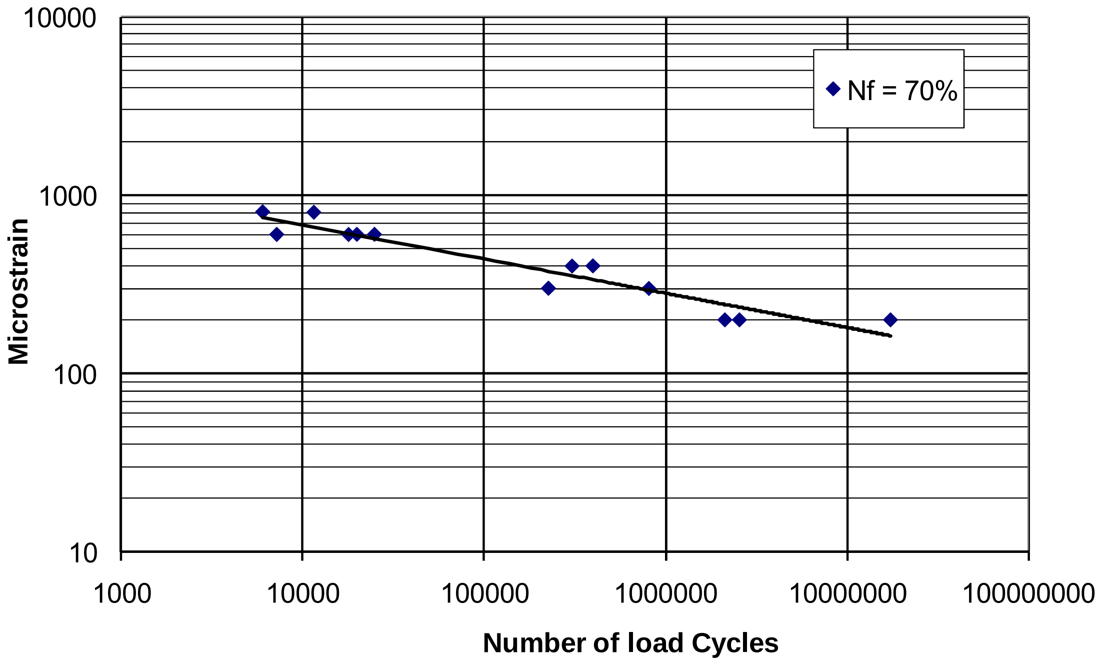

Figure 6: Fatigue results for HiMA mix.

3.6 Tentative performance specifications for HiMA

The tentative performance specifications developed based on the experimental work are shown in Table 8. The criteria require validation through accelerated pavement testing (APT). An APT programme is planned for the next phase of the HiMA T^2 project.

Table 8: Tentative performance criteria for HiMA bases

Property	Test	Method	Performance requirements	
			Class 1	Class 2
Workability	Gyratory compactor, air voids after 45 gyrations	ASTM D6926	≤ 10%	≤ 6%
Moisture sensitivity	Modified Lottman	ASTM D4867	Refer Table 7	Refer Table 7
Permanent deformation	RSST-CH, 55°C, 5 000 repetitions	AASHTO T 320	≤ 1.1% strain	≤ 1.1% strain
Dynamic modulus	Dynamic modulus test at 10 Hz, 15°C	AASHTO TP 62	≥ 14 GPa	≥ 14 GPa
Fatigue	Beam fatigue test at 10 Hz, 10°C, to 70% stiffness reduction	AASHTO T 321	≥ 310 με for 10 E6 reps	≥ 410 με for 10 E6 reps

4. STRUCTURAL DESIGN

Currently there are no damage models available for the structural design of pavements containing a HiMA base layer. Damage models for the prediction of rutting and fatigue of HiMA will be developed as part of the revision of the SAPDM. At this stage the structural performance of HiMA can only be assessed in terms of the influence of its high stiffness on the overall pavement response. The average and minimum specified layer thicknesses of HiMA are provided in Table 9. The layer thickness of HiMA is generally thinner than typically specified for bitumen-treated base courses (BTBs) or large-aggregate mixes for bases (LAMBs). This is due to the smaller stone size used in HiMA.

Table 9: HiMA base layer thickness

D [mm]	Average thickness [mm]	Minimum thickness [mm]
10	60 to 80	50
14	70 to 130	60
20	90 to 150	80

A number of pavement structures including layers with the properties of HiMA were analysed as part of the T^2 project. The results show that due to the higher stiffness of the material, base thicknesses can be reduced by approximately 30% without compromising the protection of the underlying layers.

5. CONCLUSIONS

An interim design method for High Modulus Asphalt (HiMA) was presented in this paper. The performance based methodology is complete and covers all aspects of the mix design using South African test methods. The mix design guideline was developed based on comparative laboratory testing only. The interim performance criteria were set based on a small number of mix designs and need to be further validated. The design method also requires validation by means of accelerated pavement testing and field trials before it can be implemented for large scale pavement projects.

Damage models for the prediction of rutting and fatigue of HiMA material are in progress as part of the revision of the South African pavement design method.

ACKNOWLEDGEMENTS

The work presented in this paper was made possible by the sponsorship of the Southern African bitumen association.

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KEY WORDS
Performance based specifications, high modulus asphalt, EME