CONSTRUCTION OF A HIGH MODULUS ASPHALT (HiMA) TRIAL SECTION ETHEKWINI: SOUTH AFRICA'S FIRST PRACTICAL EXPERIENCE WITH DESIGN, MANUFACTURING AND PAVING OF HIMA

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ABSTRACT

A trial section was paved with the recently introduced High Modulus Asphalt (HiMA) technology on South Coast road in eThekwini (Durban). The trial section forms part of an effort to transfer HiMA technology to South Africa, in an initiative aimed at increasing the options available for the design of heavily trafficked pavements. Apart from rehabilitation of the road, the aim of the project was to monitor the performance of the innovative pavement material. The project is the first full implementation of the technology and follows the development of the preliminary mix design and structural guidelines for HiMA.

A pavement structure including a HiMA base layer was designed for the rehabilitation of the section of the South Coast road, which had experienced severe rutting due to high volumes of trucks accessing the Durban harbour. The trial section comprises approximately 300 m of the north bound lanes, towards the intersection with Bayhead road. Approximately 190 mm of the existing pavement structure was milled out and replaced by two 80 mm HiMA as base layers, and 30 mm Stone Mastic Asphalt (SMA) as surfacing layer.

The objective of this paper is to present the process that was followed in the first design and construction of a HiMA pavement in South Africa and the observations made during the construction process. Various challenges that were and lessons learned during the project are presented. The completed section shows that HiMA can be successfully designed, manufactured, and paved in South Africa.

1 INTRODUCTION

The HiMA, or Enrobés à Module Elevé (EME), technology was developed in France in the early 1990s. It is currently used extensively on heavily trafficked main routes, major urban roads as well as runways and taxiways in airports. HiMA combines good performance in terms of rutting resistance (permanent deformation), high structural stiffness and fatigue resistance, with impermeability and durability. The key characteristics that define HiMA are a high binder content of hard bitumen with a penetration value of between 10 and 25 blended with good quality, fully crushed aggregates.

In an initiative aimed at increasing design options for heavily trafficked roads, HiMA technology was recently introduced to South Africa by means of a Technology Transfer (T^2) project. As part of the project, guidelines for the design of HiMA mixes and the design

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of pavements containing HiMA layers were developed (Denneman et al 2011a,b) Following this initiative, a heavily trafficked road section, carrying an estimated 8000 E80s per day was identified as a suitable trial section for the technology (Denneman et al, 2011c). The project comprised the rehabilitation of the North bound lanes of South Coast road towards the intersection with Bayhead road, near the entrance of the harbour. The asphalt surfacing at the intersection was severely rutted due to high volumes of heavy vehicles on route to the harbour, as presented in Figure 1a. The use of HiMA technology was proposed not only to ensure a longer life road section that will be able to carry the significant traffic volumes and loads, but also to offer a solution that would result in reduced life-cycle costs and require less maintenance. The implementation of HiMA on such a high demand road section will not only reduce the rapid occurrence of permanent deformation but also provides a test section for validation of the technology in the field as part of the HiMA T^2 project.

(a) Severe deformation under continuous heavy traffic (b) Traffic situation at the intersection

Figure 1: Pavement condition and traffic situation prior rehabilitation

This paper presents the practical experience that was gained with the design and paving through the construction of the HiMA trial section at South Coast road and observations made during the construction process. The design of the HiMA mix is discussed in Section 2, followed by a discussion on the design of the pavement structure in Section 3. Observations made during the construction of the trial section are presented in Section 4 and finally concluding remarks are made in Section 5.

2 HiMA TRIAL MIX DESIGN

The structural design of the pavement was based on recommendations set in the interim guideline and the mix design process involved the use of HiMA performance related specifications (Denneman et al, 2011b). The purpose of performance specifications is to evaluate the mix properties in the relation to the loading and environmental conditions to which the material will be subjected when placed in the field. This ensures a cost effective design, with an efficient use of natural resources without compromising the performance of the mix when placed in the field. The first step involves selecting 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, which is similar to the film thickness parameter.

Using the 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 criterion is met, specimens are compacted and subjected to a durability test. The remaining performance criteria relate to a minimum dynamic modulus of elasticity requirement, a minimum level of resistance to permanent deformation and finally a minimum fatigue life. The different steps in the process are discussed in the interim design guideline by Denneman et al (2011b).

Trial blends were developed and optimized for both design grading and binder content. The original mix design contained 20% of Reclaimed Asphalt (RA) but after the first layer was paved it was agreed to use all virgin materials in the mix for the remaining layers. This was done due to high variations encountered in the plant grading related to the RA material. The binder content selected for the trials was 5.3% of the 10/20 penetration grade bitumen. The proportions of the various materials used in the mix are shown in Table 1.

The design grading for the optimized blend is shown in Figure 2 and falls within the envelopes proposed in the HiMA design guideline. The grading is classified as fine graded mix according to Bailey method principles at approximately 70% of coarse aggregate loose unit weight. (Vavrik et al, 2002)

Table 1: Materials used in the HiMA mix

Aggregate: Nominal size (mm)	Type	Proportion (%)
19	Quartzite	25
13.2	Quartzite	9
9.5	Quartzite	9
Crusher dust	Tillite	54
Plant filler	Quartzite	2
Mineral filler	Hydrated lime	1
Bitumen	10/20 Pen	5.3

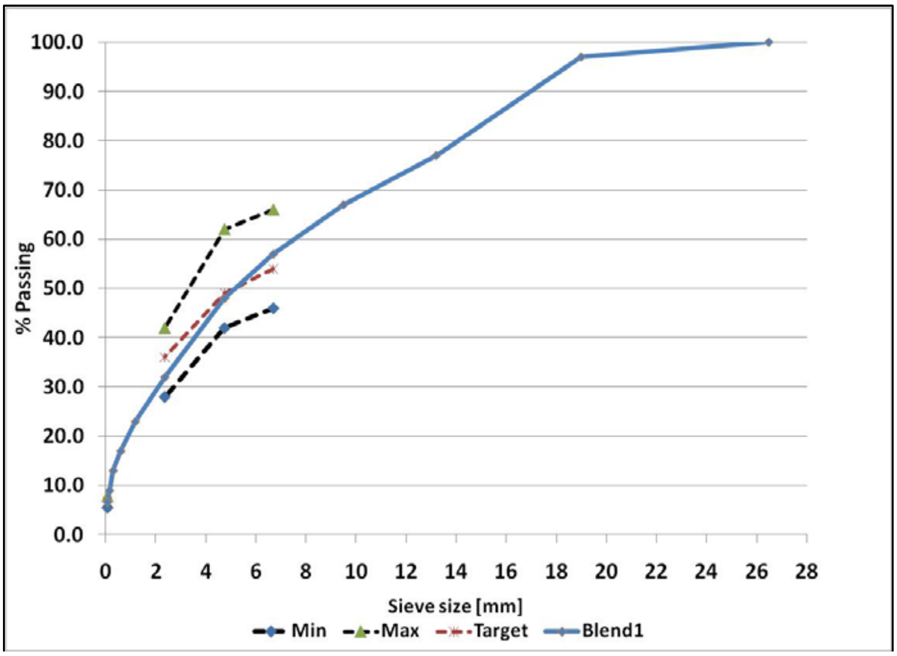

Figure 2: HiMA design compared to grading guideline

3 DESIGN OF PAVEMENT STRUCTURE

The overall work consisted of milling off the existing severely rutted asphalt surfacing layer. The pavement was milled off to the level of the old underlying macadam base, to the depth of approximately 190 mm. The milled out material was replaced with a 160 mm thick HiMA base placed in 80 mm lifts (lower and upper base). It was proposed to use a 30 mm SMA layer as a surfacing, mainly to provide fuel resistant surfacing in order to minimize potential deformation as a result of oil and fuel spillages at the intersection. Figure 3 shows the proposed pavement structure in both fast and slow lanes.

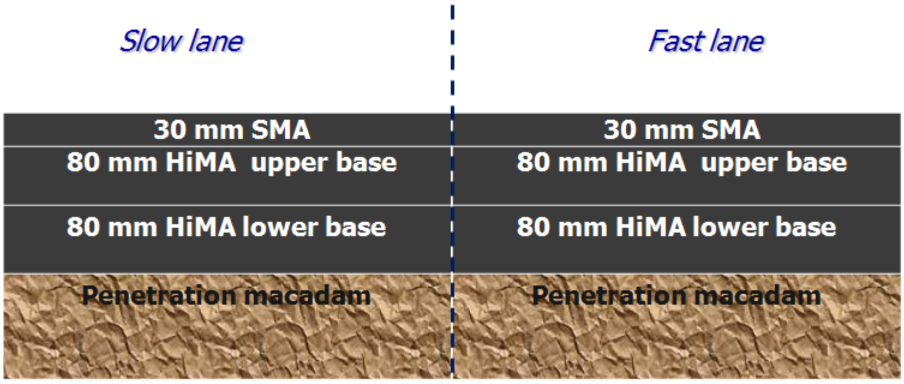

Figure 3: Diagram showing the proposed HiMA pavement for the trial section

The subsequent sub-sections summarize the process that was followed in the design of the pavement structure.

3.1 Assessment of the existing pavement condition

Core samples were taken from different positions on the section exhibiting extensive rutting in order to assess the extent of the current distress on the road and to examine the condition of the underlying layers. The drilled cores indicated that the pavement consists of numerous asphaltic layers of varying thicknesses. The densities of the cores showed low air void levels in the base layer. This was an indication that the existing material had densified to such an extent that it had become unstable and susceptible to deformation. The macadam underneath the asphaltic base appeared to be in a poor state, hence it was considered to have reached an equivalent granular condition for the back-calculation analyses.

3.2 Estimation of the layer thickness and stiffness of the existing asphalt

Based on the data obtained for the cores, the thickness of the combined layer of the existing asphalt was found to be 165 mm on average. Falling weight Deflectometer (FWD) measurements performed on the section were used to calculate the stiffness of the existing pavement layers. For back-calculation, the different asphaltic layers were combined into a single layer; the underlying layers were treated as a granular material forming a semi-infinite layer. Table 2 shows a summary of back-calculated stiffness values for the pavement layers for both fast and slow lanes.

Table 2: Results of back-calculation for stiffness

Layer number	Material	Thickness (mm)	Stiffness (MPa)			
			Fast lane		Slow lane	
			Average	Standard deviation	Average	Standard deviation
1	Combined AC and BTB	165	6600	2800	5000	3000
2	Subgrade	Semi-infinite	200	45	200	40

3.3 Structural analysis of the proposed pavement structure

The first step in the analysis was to assess the climatic condition in the area, to provide an indication of the design temperatures. The average annual minimum pavement temperature and the maximum 7 day average temperature were determined from analysis using CSIR ThermalPADS. The minimum temperature represents the worst case temperature for fatigue cracking while the maximum average temperature represents the worst case for rutting (permanent deformation). The calculated pavement temperatures were 11 °C (annual minimum) and 51 °C (average 7 day maximum). The average annual pavement temperature for the region was calculated to be 32 °C

A rough estimation of the design traffic for the section was made based on limited data. Daily traffic counts were performed on the section from 6h00 to 18h00. The data was very limited in terms of realistic estimation of the Annual Average Daily Truck Traffic (AADTT). A prediction of future growth in traffic was therefore omitted due to the limited information. The number of E80s per lane was estimated to be 8000 per day. Thus, an equivalent traffic of approximately 90 million E80s is expected for a period of 20 years (Technical Recommendations for Highways, TRH 16 1991). An indication of the traffic intensity on the section is provided in Figure 1b.
The structural analysis was performed using the n-layer linear elastic analysis software mePADS. The analysis was performed using a dual wheel load of 20 kN per wheel, at 350 mm spacing, with a contact stress of 650 kPa. The loading frequency required for stiffness calculation of the HMA layers was calculated to be 14 Hz, based on an average speed of 10 km/h assumption for trucks approaching the intersection

3.4 Structural analysis results and prediction of pavement life

The average and minimum specified layer thicknesses for a 19 mm nominal maximum particle size HiMA base is 80 mm. This provided the basis for the selection of HiMA layer thickness. A total base layer thickness of 160 mm was selected for practical purposes, to fully replace the existing asphalt layers. The advantage of a thicker base layer is that it will create a more durable structure from both a permanent deformation and fatigue perspective. It further reduces the risk of premature pavement failure due to reflective cracks propagating from the existing layers rather than due to permanent deformation. The life of different pavement layers were predicted using the damage models in MePADS. The modulus of the HiMA material was set to 13 500 MPa at a temperature of 32 °C (i.e. the average pavement temperature for the region) and a load frequency of 14 Hz. The methodology followed to develop a master curve for the HiMA material based on dynamic modulus testing is described in Anochie-Boateng et al (2010). The fatigue lives of both the upper and lower HiMA base layers were found to be more than 100 million standard load repetitions. Thus, the predicted life of the total structure assuming 8000 E80s daily is equivalent to 35 years.

Currently, no validated South African design model for the prediction of permanent deformation in asphalt is available. Validation of permanent deformation models for South Africa is in process as part of the revision of the South African pavement design method (SAPDM) (Denneman et al, 2011d,e). Recently, Anochie-Boateng and Maina (2012) proposed a new permanent deformation model for asphalt mixes in South Africa. This model has also not been validated although a laboratory verification result was very promising. For this study the Mechanistic Empirical Design Guide (MEPDG) (NCHRP, 2004) model was used to predict the permanent deformation in the HiMA layer. The final calibrated model against laboratory and field data for the relation between elastic and plastic strain in MEPDG is shown Equation 1.

$$\frac{\varepsilon_{\mathrm{p}}}{\varepsilon_{\mathrm{r}}} = k_1 * 10^{-3.4488} T^{1.5606} N^{0.479244} \quad (1)$$

Where:

ε_p = the accumulated plastic strain,
ε_r = the resilient strain,
T = temperature (°F),
N = the number of load repetitions, and
k_1 = a function of the total asphalt thickness (h_{ac}) and depth to correct for confining pressure.

4 MAIN OBSERVATIONS DURING MANUFACTURING AND CONSTRUCTION

The mixing temperature was set to 175°C based on the results of temperature and viscosity relationship tests. Compaction of the HiMA mixes was carried out using 10 ton vibratory steel wheel roller and a 22 ton Pneumatic Tyre Roller (PTR) in the field. Each 80 mm HiMA layer in each lane was satisfactorily compacted to the required minimum 94% of Maximum Theoretical Relative Density (MTRD), generally using an average compaction effort of three roller passes.

4.1 General Observations made during manufacturing and paving of the trials

Milling out the existing bituminous layers was the first activity during construction as shown in Figure 4. The thicknesses of the existing base layers were variable and as a result the macadam subbase layer was partially milled in some areas to reach the desired levels. To achieve a smooth surface, a scratch coat (medium continuous mix) was placed in areas where breakages occurred to level out the surface as shown in Figure 5.

Figure 4: Milling of the existing asphalt layers

Figure 5: Milled out section levelled with a scratch coat for a smooth surface

The lower HiMA base layer in the fast lane and turning lane was paved first, followed by the upper base layer in the same lane the following day. The fast lane was then opened for traffic and then paving of the lower base layer in the slow lane commenced, followed by the upper base layer the day after. Quality control test results on the produced mixes for the first day indicated variability in grading for different batches and paving of the remaining layers was suspended hence the construction schedule was amended. It was discovered that the variability in grading was as a result of inclusion of the RA material in the mix. This problem was addressed by using only virgin aggregate for the remaining layers. It is important that the RA grading is consistent when included in the mix design.

A total of 922 ton asphalt mix was prepared in the plant and paved. The temperature recorded when leaving the plant was 170°C and 160°C on average before paving for all trials as shown in Figure 6. A tack coat was applied at 0.5 L/m^2 of 60% bitumen-emulsion prior to paving. Figure 7 shows the tack coat application prior the paving of the bottom layers. After paving, compacted density achieved was 96 to 98% of MTD on average. Where the temperature of the mix was relatively high, density was easily achieved. Mix over-compaction occurred in these areas especially for the first paved trail as shown in Table 3. Cores were taken from areas with good compaction (around 4% voids content) and over-compacted areas the day after for the purpose of performance tests, recovered gradings, binder content determination and binder specification tests. A summary of the paving results is shown in Table 3 as reported by Lewis (2011).

Figure 6: Mix temperature before the paver

Figure 7: Tack coat application

Table 3: Summary of paving results (Lewis T, 2011)

Date paved	Lane	Layer	Average dispatch temperature (°C)	Average temperature at paver (°C)	Average field voids content (%)	Average roller passes	
						Steel Wheel	PTR
30 August 2011	Fast	Lower base	173	159	2.2	3	3
3 September 2011	Fast	Upper base	171	160	5.8	3	3
5 September 2011	Slow	Lower base	169	165	3.2	3	3
6 September 2011	Slow	Upper base	171	160	4.2	3	3

Minimal problem areas were observed except for minor segregation identified at certain chainages. No flushing was observed; the paved mat appeared homogenous throughout as shown in Figures 8. Figure 9 shows the finished off SMA surfacing and opened to traffic.

Figure 8: Finished surface of HiMA layers

Figure 9: Finished surface of the road after SMA surfacing

4.2 Quality control tests

The full results for quality control tests and performance tests are contained in the construction report by Nkgapele and Denneman (2011). After each paved layer, cores were taken for determining densities in the laboratory. The results shown in Table 4 indicated that the first paved layer (bottom layer in the fast lane) was generally over-compacted. After exclusion of the RA fraction the paving of the later layers was more consistent with the required field voids achieved.

Table 4: Density results for each layer paved

Layer	Core number	Average MTRD per trial	Corelok air voids (%)	TMH1 air voids (%)
Bottom fast lane	C1	2.462	3.9	3.6
	C2	2.462	3.2	2.9
	C3	2.462	1.6	1.1
	C4	2.462	2.5	2.1
	C5	2.462	2.0	1.7
	C6	2.462	2.4	1.4
	C7	2.462	2.6	2.3
	C8	2.462	3.0	2.4
Top fast lane	76	2.490	5.0	4.6
	77	2.490	5.7	5.4
Bottom slow lane	78	2.468	4.1	3.6
	79	2.468	3.2	3.1
Top slow lane	80	2.472	5.6	4.9
	81	2.472	3.5	3.1

The recovered grading results of mixes for each of the trial days, as shown in Figure 10, indicated that the mix gradings follow the target (design) grading closely. However, there was a slight tendency for the gradings of the trial mixes to be coarser than the target grading, especially on the final day of paving.

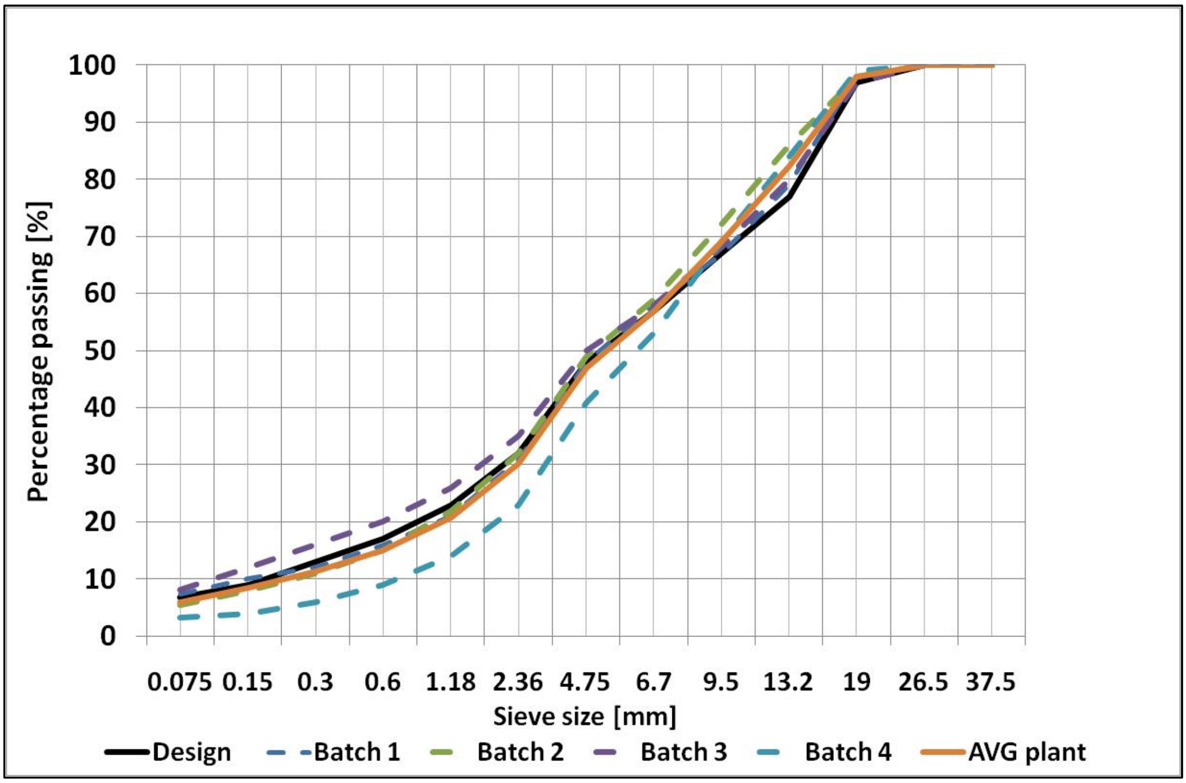

Figure 10: Grading results for first day trial (lower base layer, fast lane)

Tests on the recovered binder were performed to allow tracking of the ageing of the binder over time. Table 5 shows the results obtained for the road cores extracted from each layer paved. The binder content of the paved trials was generally low compared to the target binder content of 5.3% as shown in Table 5. It also appears that the mix paved last (upper base layer in slow lane) was stiffer than the mix paved first (lower base layer in fast lane).

Table 5: Recovered binder results

Properties	Lower layer fast lane	Upper layer fast lane	Lower layer slow lane	Upper layer slow lane
Binder content (%)	4.9	4.2	4.8	4.7
Penetration@ 25 ºC (10^{-1} mm)	20	Not tested	Not tested	17
Softening Point (ºC)	64.8	Not tested	Not tested	70.8
(Viscosity @ 135ºC, (Pa.s))	1.55	Not tested	Not tested	2.74

5 SUMMARY AND CONCLUSIONS

The successful completion of the current HiMA project is an improvement in technology transfer after the development of the interim design guideline for HiMA mixes in South Africa. It is expected that the paved HiMA trial section will require less frequent maintenance. Some of the challenges and lessons learnt during the manufacturing and paving include the following:

- The paved trial mixes had a tendency for low binder contents compared to the target during manufacturing but no difficulty was experienced in obtaining compaction densities during the paving.
- In some areas, the mix showed some tendency for over-compaction, resulting in flushing (bleeding) on the surface.
- Another characteristic of HiMA that was evident is that it tends to stiffen suddenly under the rollers, as the temperature of the layer decreases resulting in little effect on compaction.
- Laboratory testing on the cores indicated that the exclusion of recycled asphalt material for the paved layers did not affect the rutting performance of the mix.

The behaviour and properties of the HiMA mixes with the inclusion of RA still needs to be investigated in order to obtain a broader perspective of their use. Further data will be gathered during the long term pavement performance (LTPP) monitoring on the trial section every 6 months over a period of 2 years. The data collated will be used later to validate the mix design methods, and calibration of performance models for structural design of HiMA.

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7 REFERENCES

Anochie-Boateng, J., and Maina, J. (2012). *Permanent deformation testing for a new South African mechanistic pavement design method*. Construction and Building Materials 26, 541–546.

Anochie-Boateng, J., Denneman, E., O'Connell, J. and Ventura, D. 2010. *Hot-mix asphalt testing for the South African pavement design method*. Proceedings of 29th Southern Africa transportation conference, Pretoria, pp. 111-128.

Delorme, J., De La Roche, C., and Wendling, L. 2007*. LPC Bituminous Mixtures Design Guide*. Director. Paris: Laboratoire Central des Ponts et Chaussees.

Denneman, E., Nkgapele, M., Anochie-Boateng, J.; Maina, J.W., 2011a. *Transfer of high modulus asphalt technology to South Africa*, Proceedings of the 10th Conference on Asphalt Pavements for Southern Africa., Champagne Sports Resort, KwaZulu-Natal, South Africa.

Denneman, E, Maina, J.W., and Nkgapele, M. 2011b. *Interim guide for the design of high modulus asphalt mixes and pavements in South Africa.* v1.1, Prepared for Sabita, CSIR, Pretoria.

Denneman, E., Nkgapele, M. and Komba, J. 2011c. *Implementation of High Modulus Asphalt technology at South Coast Road in eThekwini*, Report: CSIR/BE/IE/ER/2011/0048/C Prepared for Sabita, CSIR, Pretoria.

Denneman, E., Anochie-Boateng, J., Nkgapele , M. and Komba, J. 2011d. *Revision of damage models for asphalt pavements*, Paper submitted for the 10th Conference on Asphalt Pavements for Southern Africa (CAPSA), Central Drakensberg.

Denneman, E., Nkgapele, M., Maina, J.W., Komba, J., Verhaeghe, B.M.J.A., and Du Plessis, L. 2011e. *High Modulus Asphalt Technology Transfer: Final report Phase 2*, Report: CSIR/BE/IE/ER/2011/0066/B Prepared for Sabita, CSIR, Pretoria.

NCHRP, 2004. *Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, NCHRP1-37, http://www.trb.org/mepdg/guide.htm

Lewis, T. 2011. *Brief report on High Modulus Asphalt trials in Durban*, Report Prepared for Sabita, TLC, Durban.

Nkgapele, M. and Denneman, E. 2011. *High Modulus Asphalt trial South Coast Road: Construction report*, Report: CSIR/BE/IE/ER/2011/0061/C Prepared for Sabita, CSIR, Pretoria.

Technical Methods for Highways (TMH 1). 1986. "*Method C2: The determination of the resistance to flow of a cylindrical briquette of a bituminous mixture by means of Marshall apparatus*." Department of Transport, Pretoria, South Africa.

Technical Recommendations for Highways (TRH 16). 1991. "*Traffic loading for pavement and rehabilitation design*." Department of Transport, Pretoria, South Africa.

Vavrik, W.R., Huber, G., Pine, W.J., Carpenter, S.H., Bailey, R., 2002. *Bailey Method for Gradation Selection in Hot-Mix Asphalt Mixture Design*. Transportation Research E-Circular, Number E-C044, October 2002, Washington.