High modulus asphalt (EME) technology transfer to South Africa and Australia: shared experiences

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***Abstract*— The paper describes experiences with the implementation of French enrobés à module élevé (EME) (high modulus asphalt) technology in South Africa and Australia. Tentative performance specifications for EME mixes were set in the two countries based on comparative testing using French, South African and Australian test methods. An overview of the development of the performance requirements from laboratory experiments is presented. Trial sections with EME technology were also constructed in both countries. Important findings from the field trials, in terms of mix design, manufacture and placement, and structural performance of EME are reported in the paper. The experiences with EME to date indicate that this stiff, rut and fatigue resistant asphalt technology provides real opportunities to build more sustainable and/or thinner asphalt pavements for heavy traffic loading situations. The analysis in this paper of the combined experimental work conducted in South Africa and Australia further support the specification limits for EME mix design.**

***Keywords*— EME, high modulus asphalt**

I. INTRODUCTION

EME technology was developed in France in the early 1990’s which is now used extensively on main routes, airports and urban roads both in mainland France and overseas territories. The distinctive component of EME mixes is a very hard paving grade bitumen applied at a high binder content (approximately 6 mass%). The material is typically used in the construction of asphalt base layers. Compared to conventional asphalt bases with unmodified binders, high modulus asphalt is characterised by a high stiffness, high durability, superior resistance to permanent deformation and good fatigue resistance. International experience indicates that significant pavement thickness reductions can be achieved using EME2. It also suitable for the strengthening of pavements in areas where there are restrictions to pavement thickness (e.g. kerb and channel levels in urban areas, bridge crossings on motorways, etc.).

In both South Africa and Australia, EME technology has successfully been implemented following research efforts to transfer the technology from France. Similar technology transfer approaches were followed in the two countries. The objective of this paper is to present the combined experience with EME technology for the benefit of asphalt industry stakeholders in both countries.

The South African interim design procedures for EME were incorporated into SABITA Manual 33 [1]. The development of the interim specifications was described in a paper at the previous CAPSA [2]. The Australian interim mix design specifications, as well as their development was recorded in Austroads publication AP T283 14 [3].

II. Development of mix design specifications

The technology transfer efforts in both South Africa and Australia used similar approaches in converting French specifications for EME to local criteria. Comparative testing was performed on the same mix design in France and in the adoptive countries.

In South Africa, an extensive laboratory study was conducted to translate the French performance specifications for EME 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.

For the Australian technology transfer effort, materials for an existing and widely used French EME mix design were shipped to the ARRB laboratory in Melbourne. The performance of this mix in terms of the French performance criteria was known. At ARRB the material was subjected to the Australian equivalent tests for the relevant performance related design parameters. Based on this exercise an initial set of data was obtained to benchmark EME mix performance in Australian test methods. Meanwhile, various Australian asphalt producers were having EME mix designs developed for Australian materials, which were sent to France. Once the mix designs were completed, a set of performance tests were performed in Australia. The datasets containing both French and Australian test results for the mixes were submitted to the Austroads EME working group to support the development of interim specifications.

The design of EME differs from more conventional volumetric type asphalt mix design in both South Africa and Australia in that it is strictly performance based. A comparison of the French, South African and Australian field related performance criteria are discussed in individual sections below. In South Africa it was decided to develop mix design requirements for both EME Class 1 and Class 2, although it has become evident that Class 2 only will be the preferred material. In Australia, only the more fatigue resistant Class 2 was considered of relevance for technology transfer by local stakeholders.

A. *Workability*

The first performance criterion for EME 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 12697-31). 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 12697-31 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 former uses an angle of 1.25°; the latter requires 0.82°. The South African workability criteria for EME were therefore set based on a comparative testing using European and SUPERPAVE requirements. In Australia the decision was taken to use the European settings for gyratory compaction. The workability requirements are shown in Table I.

TABLE I. Workability criteria

Country	**Test**	**Method**	**Performance requirements**	
			Class 1	Class 2
France	Gyratory compactor, air voids after 100 gyrations	EN 12697-31	≤ 10%	≤ 6%
South Africa	Gyratory compactor, air voids after 45 gyrations	ASTM D6926	≤ 10%	≤ 6%
Australia	Gyratory compactor, air voids after 100 gyrations	Based on EN 12697-31	N/A	≤ 6%

B. *Moisture sensitivity*

The moisture sensitivity of EME is assessed in France using an unconfined compressive test (EN 12697-12) on moisture conditioned specimens (Duriez test). In both South Africa and Australia, the modified Lottman test is generally used for this purpose. In both countries it was deemed unnecessary to develop separate durability criteria for EME, instead existing criteria for conventional hot mix asphalt were used. This led to a single minimum TSR requirement of 0.8 has been set for all climatic zones, in both South Africa and Australia. The moisture sensitivity criteria are shown in Table II.

TABLE II. Moisture sensitivity criteria

Country	**Test**	**Method**	**Performance requirements**	
			Class 1	Class 2
France	Duriez	EN 12697-12	0.7	0.7
South Africa	Modified Lottman (including freeze-thaw)	ASTM D4867	0.8	0.8
Australia	Modified Lottman (including freeze-thaw)	AGPT T232	N/A	0.8

C. *Resistance to permanent deformation*

The resistance against permanent deformation (rutting) of the EME is assessed in France by means of a large wheel tracking tests on slabs in accordance with EN 12697-22. The equivalent test method selected in South Africa was the Repeated Simple Shear Test at Constant Height (RSST-CH). The test is performed in accordance with the AASHTO 320-03 protocol. In Australia a small wheel tracking device also known as the 'Cooper Wheel Tracker' run in accordance with AGPT/T231 is the standard permanent deformation test for asphalt. The permanent deformation mix design requirements are shown in Table III.

TABLE III. RESISTANCE TO PERMANENT DEFORMATION

Country	**Test**	**Method**	**Performance requirements**	
			Class 1	Class 2
France	Wheel tracking (large device) at 60 °C and 30 000 cycles	EN 12697-22	≤ 7.5% strain	≤ 7.5% strain
South Africa	RSST-CH, 55°C, 5 000 repetitions	AASHTO T320-03	≤ 1.1% strain	≤ 1.1% strain
Australia	Wheel tracking (small device) at 60 °C and 30 000 cycles	AGPT T231	N/A	≤ 6.0 mm

D. *Minimum stiffness criterion*

The French specifications for EME require a minimum modulus of 14 GPa at a temperature of 15°C and a loading frequency of 10 Hz. The modulus is determined in two point bending test configuration. In South Africa the dynamic modulus test in accordance with AASHTO TP62 was used to set specification limits for the material. In Australia, four point bending testing was used. The modulus requirements are summarized Table IV

TABLE IV. MINIMUM STIFFNESS

Country	**Test**	**Method**	**Performance requirements**	
			Class 1	Class 2
France	Two point bending flexural modulus 15°C, 10 Hz	EN 12697-26	≥ 14 GPa	≥ 14 GPa
South Africa	Dynamic modulus test at 10 Hz, 15°C	AASHTO TP 79	≥ 16 GPa	≥ 16 GPa
Australia	Four point bending flexural modulus 15°C, 10 Hz	AGPT/T274	N/A	≥ 14 GPa

E. *Fatigue resistance*

The French fatigue specifications for EME apply two point bending fatigue at 10°C, 25 Hz, tests are run in sinusoidal displacement mode. Both South Africa and Australia use four point bending test configuration for fatigue resistance. Until recently, fatigue testing in Australia was performed in haversine loading configuration. Recently however, it was confirmed that haversine displacement control testing using the AGPT/T233 protocol in effect results in a sinusoidal strain response of half the intended amplitude. As a consequence, tests run at a given haversine strain amplitude under AGPT/T233 will result in a similar number of load repetitions to failure of a test run at half the strain amplitude in sinusoidal displacement mode. Since the fatigue models used in the Austroads Guide to Pavement Technology were developed based on sinusoidal fatigue testing, it was proposed to change the loading mode in the test method from haversine to sinusoidal [4]. An updated test method was published as AGPT/T274-15. In South Africa it has become evident since the first introduction of EME that mixtures developed did not meet the fatigue criteria contained in Sabita Manual 33 and presented at the previous CAPSA [2], whilst complying with the French requirements when tested in France according to EN12697-24. Based on further benchmarking work against French mix design and analysis of data collected over the past three years in South Africa, revised fatigue criteria have been adopted [10]. The current fatigue requirements in the various countries are shown in Table V.

TABLE V. FATIGUE REQUIREMENTS

Country	**Test**	**Method**	**Performance requirements**	
			Class 1	Class 2
France	Two point bending 10 °C, 25 Hz to 50% stiffness reduction	EN 12697-24	≥100µε for 10 E6 reps	≥130µε for 10 E6 reps
South Africa	Four point bending at 10 Hz, 10°C, to 50% stiffness reduction	AASHTO T 321	≥ 210 µε for 10 E6 reps	≥ 260 µε for 10 E6 reps
Australia	Four point bending at 20 °C, 10 Hz to 50% stiffness reduction	AGPT/T274	N/A	≥150µε for 10 E6 reps

III. CONSTRUCTION OF TRIAL SECTIONS

EME demonstration trials were constructed in South Africa and Australia. This section summarizes the trial configurations and the initial findings.

A. *Trials with EME in South Africa*

Implementation of EME technology in South Africa started in 2011. A trial section (approximately 300 m long) consisting of an EME D20 base layer was constructed on the heavily trafficked South Coast Road in Durban. The section is a major entry route for heavy vehicles to or from the Durban harbour. Several attempts to rehabilitate the section using conventional asphalt mixes had failed as a result of premature rutting due to the heavy traffic volumes entering the Durban harbour.

Details on the pavement structural design and evaluation of the EME mix can be found in [5]. The existing severely rutted asphalt was milled off to a depth of approximately 190 mm. The milled out asphalt was replaced by a 160 mm EME base layer, which was constructed as two separate layers (80 mm each). The EME base layer was surfaced with a 30 mm SMA wearing course (EVA-modified bitumen) to provide fuel resistance in order to minimise potential deformation as a result of fuel spillages from trucks entering the Durban harbour.

Among the lessons learned during the construction of the trial section is that the EME mix is fairly easy to compact in the field. However, the EME mix tends to stiffen very suddenly with decrease in temperature, resulting in little further effect on compaction.

The field performance of the South Coast Road trial section was monitored over a period of two years. The assessment of the field performance of the trial section consisted of visual condition surveys, deflections measurements, macro-texture measurements, and roughness measurements. The deflections measurements were performed using a Falling Weight Deflectometer (FWD) using a 40kN load, whereas as macro-texture and roughness measurements were performed using a digital high-speed laser profiler.

At the end of the two-year monitoring period, the trial section appeared to be performing well after having been heavily trafficked over this period of two years. The traffic carried by the trial section was estimated at 9.3 million equivalent standard axle loads (E80s) over the two year period. The only distress observed were bleeding, aggregate polishing and densification of the SMA surfacing due to heavy traffic loading. However, the observed distresses appeared to be limited to the SMA surfacing only, with no indication of structural damage of the EME.

Fig 1 show photos of the trial section prior to the rehabilitation and two years after rehabilitation. Figs 2 and 3 show the rut depth and the maximum deflection measurements in the right lane of the EME trial section, respectively. The measured pavement surface temperatures are also plotted in Fig 3. The complete set of monitoring results can be found in the Long-Term Pavement Performance (LTPP) monitoring of the trial section final report [6]. Although the EME trial section was monitored for a period of two years only, the field assessment results suggest that EME can withstand heavy traffic volumes without significant structural distress. Based on the monitoring results, the use of EME on the heavily trafficked roads should be encouraged. Recently, EME was used for rehabilitation of a section of the N3 highway.

(a) Severe rutting on the South Coast Road section prior to rehabilitation

(b) Condition of the South Coast Road section two years after rehabilitation

Fig. 1. Condition of the EME trial section prior and two years after rehabilitation

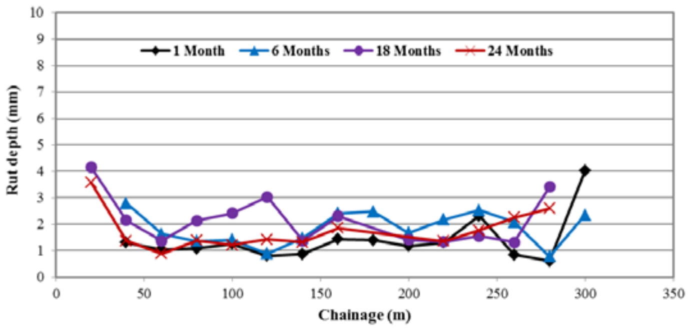

Fig. 2. Rut depth measurements on the EME trial section at South Coast Road

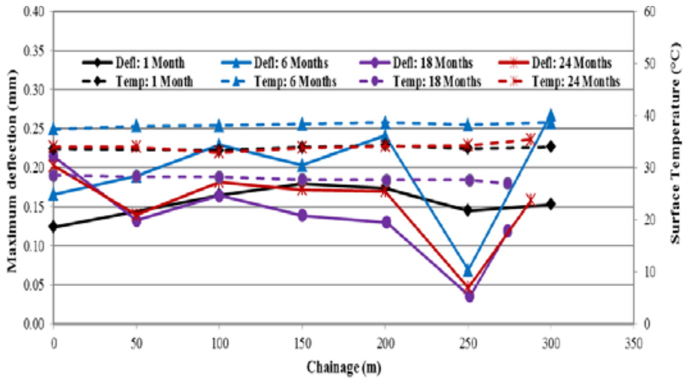

Fig. 3. Maximum deflections measurements on the EME trial section at South Coast Road

In terms of other applications of EME in research, in June 2013 a significant number of instrumented experimental sections were constructed by the South African National Roads Agency Ltd (SANRAL) on road R104 near Pretoria. The experimental sections included three asphalt base course sections of 100mm EME, 150mm EME and 150mm conventional Bituminous Treated Base (BTB). All three sections were surfaced with a 40mm medium continually graded asphalt wearing course. The main purpose of these three experimental sections was to better understand the effects of temperature, traffic speed and loading on the resilient response of the asphalt base courses, as well as to quantify their differences in load spreading ability.

B. Australian EME trial

The execution of the first EME2 demonstration project in Australia took place on 15 February 2014 on the access road to Boral's asphalt plant at Whinstanes in Brisbane. The existing asphalt pavement layers were removed by cold planing. The trial comprised the following pavement structures:

- 100 mm thick EME base layer
- 150 mm thick EME base layer, constructed in one paving run
- 150 mm thick dense graded asphalt for heavy duty application (DG20HM) as control section.

The construction process was closely monitored, full details can be found in [3]. Fig 4 shows an example of the temperature distribution in the 100mm EME base later at time of placement. Despite concerns that the construction crew would struggle to achieve in situ density given the high viscosity of the binder (6000 Pa.s @ 60°C), the EME2 compacted readily under the vibratory 7 tonne tandem steel wheeled roller and 9 tonne vibratory PTR. Although, this was also aided by the close proximity of the site to the mixing plant, layer thickness and high ambient temperature which was above 30°C.

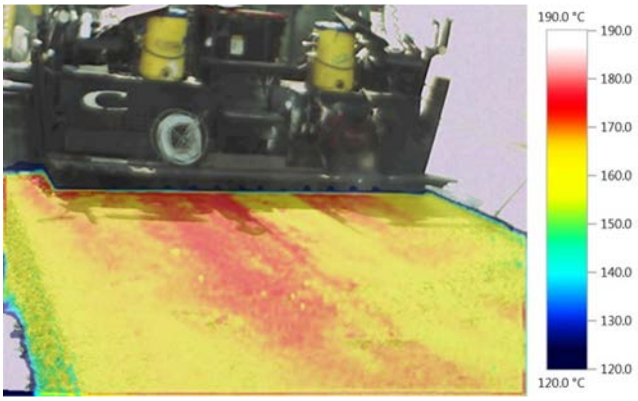

Fig. 4. Compaction temperature monitoring

One of the parameters investigated during the construction of the trial were the skid resistance properties of the EME surface. The high binder content of the EME mix and high proportion of fines combined with extensive compaction results in a fatty, binder rich surface finish. Due to the complex nature of construction sequences and traffic control requirements it is envisaged that for future EME2 projects the finished layer would be trafficked before a wearing course is added. In such a situation the skid resistance of the base layer, which would be under temporary trafficking, is critical. Since there was no local experience available whether such a surface can be trafficked, it was one of the objectives of the trial to investigate this issue. A fine grit was spread over the EME surface along part of the trial as shown in Fig 5. Subsequent comparative skid resistance testing showed that this measure was successful in improving the skid resistance of the EME surface, although in this case the skid resistance results for the EME base without grit proved acceptable for temporary trafficking as well.

Fig. 5. Gritting of the EME surface

After a short period of monitoring of the base (including the gritted surface), the wearing course, a 10 mm nominal size dense graded asphalt, with multigrade bitumen, was placed at a uniform thickness of 30 mm.

The demonstration trial had the following objectives:

- Demonstrating the feasibility of production of a compliant EME2 mix using local aggregate and bitumen, within the appropriate requirements for production control and variability
- Demonstrating the constructability and workability of EME using typical construction equipment available in Australia, as EME provides the highest performance at in situ air voids contents well below 6.0 %
- Short-, medium- and long-term monitoring of in situ performance.

The monitoring process is supported by permanent pavement instrumentation, including strain gauges (refer Fig 6), in depth temperature sensors and a weather station.

Since construction, regular FWD surveys of the pavement are performed. FWD testing is performed in difference seasons of subtropical climate in Brisbane. Since the pavement is instrumented with strain gauges and temperature probes, detailed knowledge of the in-situ performance of the material is being gained.

Fig. 6. Strain gauges being installed in the pavement

Analysis of the modulus data from laboratory and the field have shown that the base thickness of full depth asphalt pavements in Queensland can be reduced by about 20% - 25%, compared to conventional asphalt bases. While specific procedures for the design of asphalt pavements containing EME are being developed, the general Austroads pavement design approach is applied for the design of EME pavements in Queensland.

IV. Development of South African Transfer functions

In another paper at CAPSA 2015 [7] the development of transfer functions for EME in SA is described. Based on research supported by Sabita in 2014 and 2015 [8, 9] it was recommended that, inter alia, the proposed preliminary fatigue transfer functions in the interim document for the design of EME in SA[1] be evaluated and improved functions developed based on a wider range of laboratory tests and field experience from in situ EME test roads. Relevant available laboratory and field data for EME sections were collected and analysed to be incorporated into improved transfer functions. These improved EME fatigue failure transfer functions were developed and evaluated by comparing them with existing transfer functions for similar materials.

1) Fatigue

The investigations focused only on materials that falls under the basic definition of EME Class 2, being an asphalt manufactured with 10/20 (or possibly 15/25) pen grade (straight) bitumen. Additional laboratory and field tests were excluded in the project. Steyn [9] used a limited set of South African EME laboratory data (based on research by CSIR) to develop a transfer function for fatigue of EME layers (Equation 1). This provisional EME fatigue failure transfer function is based on a temperature of 10°C and a range of current EME mix designs. Evaluation of the laboratory testing of the various tests indicated relatively similar fatigue / cycles relationships.

$$\log(\mu\varepsilon) = -0.1782(\log \text{cycles}) + 3.5028 \qquad (1)$$

A comparison between the original BTB and the proposed EME transfer functions, indicates higher expected lives for the EME material, with the ratio between the EME and BTB expected lives for similar strain levels between 17 (1 000 με) and 130 (100 με). Steyn [9] indicated that the matter of the reference temperature used for the design appears to potentially be problematic, as the transfer function is based on a reference temperature of 10°C, but, comparing these to in situ service temperatures of the EME layers monitored on road R104 provides different temperature ranges. Evaluation of in situ temperatures of the EME layers on road R104 indicated in situ temperatures ranging between 14°C and 65°C (top of EME below 40 mm asphalt), and 19°C and 46°C (bottom of 100 to 150 mm thick EME). It is recommended that the potential for a shift in the transfer function based on these actual temperatures at which EME is operating be evaluated.

2) Permanent deformation

The current permanent deformation transfer function in Sabita Manual 33 [1] (Equation 2) was not changed from the original format. It appears to be very conservative and unresponsive / insensitive to any changes in the input parameters. It may be that the sensitivity of EME to permanent deformation is just so low that virtually no permanent deformation will be expected in the layer (as opposed to the permanent deformation in the whole pavement structure).

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 * 10^{-3.4488} T^{1.5606} N^{0.479244}$$

Where:

ε_p = the accumulaterd plastic strain
ε_r = the resilient strain at the middle of the layer
T = temperature (°F),
N = the number of load repetitions
k_1 = a function of total asphalt layer(s) thickness (h_{ac}) and total depth to computational point (depth), to correct for the variable confining pressures that occur at different depths. (i.e. the term "depth" = total depth to the computational point.
k_1 = $(C_1 + C_2 * \text{depth}) * 0.328196^{\text{depth}}$
C_1 = $-0.1039 * h^2_{ac} + 2.4868 * h_{ac} - 17.342$
C_2 = $-0.172 * h^2_{ac} + 1.7331 * h_{ac} + 27.428$

(2)

The currently available fatigue and permanent deformation transfer functions appear to be valid for current materials, however, more analysis need to be conducted regarding the temperature that should be used for the fatigue transfer functions and the sensitivity of the permanent transfer functions under real traffic. More material tests at similar conditions are required to generate correct confidence limits for the transfer functions, and the effect of wander should incorporate both the location of the tyre loads across the lane and the typical response of the specific pavement material under in situ conditions to the wander effect.

V. CONCLUSIONS

The objective of this paper is to present the combined experience with EME technology for the benefit of asphalt industry stakeholders in both countries. The EME technology transfer efforts in both South Africa and Australia have been a success. Similar methodologies were applied in the technology transfer in both countries. The comparative testing in the country of origin and the adoptive country led to the development of reliable performance specifications for the technology. EME offers the prospect of reduced asphalt thicknesses for heavy duty pavements, and lower construction and maintenance costs.

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REFERENCES

[1] Sabita. “Interim design procedure for high modulus asphalt.” Sabita Manual 33. ISBN 978-1-874968-62-7. Howard Place, South Africa. 2013.

[2] Denneman, E., Nkgapele, M., Anochie-Boateng, J. and Maina, J.W., Transfer of High Modulus Asphalt Mix Technology to South Africa, Proceedings of the 10th Conference on Asphalt Pavements for Southern Africa, Champagne Sports Resort, 2011.

[3] Petho, L., Beecroft, A., Griffin, J. and Denneman, E. “High modulus high fatigue resistance asphalt (EME2) technology transfer.” Austroads Publication AP-T283-14, Austroads, Sydney, Australia, 2014.

[4] Denneman, E. Review of the AGPT/T233 fatigue test protocol and its link to pavement design. Proceedings of the 15th AAPA International Flexible Pavements Conference, Brisbane, 2013.

[5] Denneman, E., Nkgapele, M. & Komba, J. 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, 2011.

[6] Nkgapele, M., Komba, J. & Verhaeghe, B. Long-Term Pavement Performance monitoring of Enrobé à Module Élevé (EME) trial section on South Coast Road in eThekwini, Report: CSIR/BE/IE/ER/2013/0069/B Prepared for Sabita, CSIR, Pretoria, 2013.

[7] Steyn, W.J.vdM., Maina, J.M., Myburgh, P. and Solomons, S. Evaluation of EME transfer functions and critical layer thicknesses. Paper submitted to CAPSA 2015. 2015.

[8] Steyn, W.J.vdM. “Report to Sabita on EME thickness design evaluation.” University of Pretoria. 2013

[9] Steyn, W.J.vdM. “Sabita EME transfer functions.” Report UP/WJVDMS/06/2014. University of Pretoria, Pretoria, South Africa. 2015.

[10] Sabita. “Technical Bulletin – update on EME testing criteria”. Howard Place, South Africa. 2015.