



Design procedure for *High Modulus Asphalt (EME)*

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excellence in bituminous products

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High Modulus Asphalt (EME)
Manual 33

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1. Contents

2. Table of Contents

1. Acknowledgements	5
2. Preface.....	6
3. Introduction	7
4. Background to introduction into South Africa	7
5. The product	8
6. Use and application	8
7. Design of EME.....	10
7.1 Principles	10
7.2 Process	10
8. Selection of Materials	11
8.1 Constituents	11
8.1.1 Aggregates.....	11
8.1.2 Filler	12
8.1.3 Binder	13
8.2 Design grading.....	14
8.2.1 Recommended gradings.....	14
8.2.2 Lift thickness and maximum aggregate size	15
8.2.3 Binder content.....	16
8.2.4 Workability	18
8.2.5 Durability	18

8.2.6	Permanent deformation	19
8.2.7	Dynamic modulus	20
8.2.8	Fatigue	20
8.3	Summary of performance requirements.....	21
9.	Structural design	22
9.1	Analysis of Pavement Structures	22
9.1.1	Climatic conditions	22
9.1.2	Traffic loading	23
9.1.3	Pavement stiffness values	23
9.2	Damage modelling.....	23
9.2.1	Fatigue	23
9.2.2	Permanent deformation.....	25
10.	Construction.....	26
11.	Use of RA in EME.....	27
12.	Bibliography	29
Appendix A:	Construction of EME	30
Introduction.....	30
A.1	Storing, manufacturing, transporting and preparation.....	31
A.1.1	Storing	31
A.1.2	Manufacturing	32
A.1.3	Transporting	33
A.1.4	Preparation	35
A.1.5	Further reading.....	39
A.2	Joints	39
A.2.1	Paving Adjacent to Existing EME	39

A.2.2	Transverse Joints	40
A.2.3	Longitudinal Joints	41
A.2.4	Stages of Cutting Longitudinal Joints	41
A.2.5	Positioning of longitudinal joints for new work	43
A.2.6	Specified layer thicknesses.....	44
A.2.7	Tacking of joints	46
A.2.8	Bitumen impregnated tape	46
A.2.9	Further reading	46
A.3	Paving	47
A.3.1	Checks during Paving	47
A.3.2	Paving equipment	48
A.3.3	Bond coat	48
A.3.4	Paving	49
A.3.5	Further Reading.....	49
A.4	Compaction	50
A.4.1	Compaction Procedures	50
A.4.2	Achieving the specified maximum field voids	50
A.4.3	Generally accepted rolling patterns	51
A.4.4	Surface flushing	51
A.4.4	Paving over bridge decks.....	52
A.4.5	Opening the road to traffic	52
A.5	Sampling of EME	52
A.5.1	At the asphalt plant	52
A.5.2	Coring	53
A.5.3	Further reading.....	53

A.6 Quality.....	53
A.6.1 Recommended temperature ranges.....	53
A.6.2 Check sheets, quality management plans, method statements	54
A.6.3 Design mix	54
A.6.4 Routine testing	55
A.6.5 Specialised testing	55

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2. Preface

This guideline has been compiled to assist practitioners in assessing the feasibility of using high modulus asphalt based on the French technology *Enrobé à Module Élevé* (EME) in pavements on highly trafficked routes e.g. urban bus routes and key motorways as well as roads subjected to high incidence of heavily laden trucks in industrial areas.

The design method presented in this document is supplementary to the method described in Sabita Manual 35: *Design and Use of Asphalt in Road Pavements*. The target performance characteristics covered in this method tie in with those required as inputs into the South African Pavement Design System being developed under the auspices of SANRAL.

This design guide is aimed at specialists experienced in the design of asphalt mixes who are also fully conversant with conventional procedures, such as those presented in Manual 35. As such this document focuses on matters that are specific or unique to EME.

Two topics that do not deal with the mix design process *per se*, but which are closely related thereto – pavement design and construction – are also covered, the latter in an appendix covering aspects that are critically important to ensure that the constructed layer will perform as expected. The section on structural design, while by no means presenting a comprehensive treatment of the subject, endeavours to give guidance on inputs into analytical pavement design procedures.

The third edition featured the adoption of the Hamburg Wheel Tracking Test for assessing resistance to permanent deformation, an expanded section on construction given in an appendix and guidance on the use of reclaimed asphalt in the manufacture of EME.

This, the fourth edition, was revised to clarify the relationship of the mass of binder expressed as a percentage of the total dry mass of aggregate, and the conventional expression of binder content used in general design and judgement of compliance procedures. It also makes a new recommendation on the mat temperature before opening to traffic or construction of subsequent lifts, as well as using the term “lift” instead of “layer” in relation to aggregate size. Additionally, the tables relating aggregate size to layer or lift thickness have been revised to reflect that the pavement layer thickness is an input parameter, with lift thicknesses and nominal maximum particle size (NMPS) emanating therefrom.

3. Introduction

The material presented in this manual is based on the French technology *Enrobé à Module Élevé* (EME), developed in the 1980's where low penetration - very hard, yet not brittle - bitumen binders are used to produce very stiff asphalt layers. The superior load spreading characteristics of these layers, together with a high resistance to permanent deformation, enable the construction of more cost-effective pavements for roads and airports exposed to severe traffic loading.

This product is recycle-friendly and has proved itself as a viable alternative to concrete base pavements in accelerated road pavement testing at the Laboratoire Central des Ponts et Chaussées (LCPC) in France as well as through experience of its use in airport pavements. Specifications for the low penetration binders used in EME are now covered in the SABS standard SANS 4001-BT1:2014. The use of these binders competes with modified binders on performance and costs - with an added benefit being the afore-mentioned recycle friendliness. The EME technology has been successfully transferred to South Africa with the assistance of the CSIR Built Environment, eThekweni Municipality and SANRAL by adhering closely to the French technology and test methods.

There are two classes of EME in the French specifications, EME Class 1 and EME Class 2, with the Class 2 material having significantly higher binder content and superior performance characteristics.

4. Background to introduction into South Africa

A requirement becoming increasingly important to road owners is the availability of pavement technologies that will limit interventions on heavily trafficked routes, thereby reducing disruptions through congestion and limiting road user delay costs to the minimum.

In 2006 Sabita recognised the need to implement flexible pavement solutions that would meet these requirements, and embarked on a technology transfer process whereby the EME technology could be introduced to South Africa.

Once such a design procedure has been standardised it is foreseen that it will be integrated with the SA Pavement Design System to enhance the options in providing economic pavements for heavy traffic applications.

This guideline contains a performance related method for the design of EME mixes in SA. The content is based primarily on studies carried out by the laboratories of Shell and Colas in France, and the CSIR. The performance tests carried out in Europe were replicated in SA, and design criteria were developed for alternative, readily available test procedures.

5. The product

In essence, EME is hot-mix asphalt consisting of hard, unmodified bitumen blended at high concentrations (up to 6,5% m/m) with good quality, fully crushed aggregate to produce a mix with low air voids content. EME is designed to combine good mechanical performance with impermeability and durability. Its key performance characteristics are high elastic stiffness, high resistance to permanent (plastic) deformation and fatigue failure, while also offering good moisture resistance and good workability.

In Europe the 10/20 and 15/25 penetration grades used in EME are frequently produced, ready-to-use refinery products. The 10/20 grade is now also available from a South African refinery.

6. Use and application

Pavements comprising EME as the principle structural layer can be employed for design traffic well in excess of 50 million ESALs - with due consideration and selection of supporting pavement materials and structure.

While EME was initially intended to be used on the most heavily trafficked routes in France, as well as on airport pavements and container terminals, one of the fastest growing potential markets of EME in Europe has been urban roads. This has translated in direct savings in road construction material usage and construction costs.

EME can be used in new construction as well as rehabilitation projects. The potential for reduced layer thicknesses makes EME also ideally suited

for application in urban areas where disruption to subsurface services can be significantly reduced. Preliminary structural analyses performed on typical SA pavements have shown that asphalt base thickness reductions of 30 – 40% can be achieved using EME. These reductions clearly are related to the actual thicknesses being considered as well as the provision of a substrate of suitable stiffness. According to French literature the superior structural properties of high modulus asphalt permit thickness reductions of 25 - 40% in French road designs compared to conventional asphalt bases.

Potential application zones of EME include:

- 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
- In rehabilitation, where between 80 and 120 mm is milled off and re placed with EME, often surfaced with a thin asphalt wearing course; and
- On airports EME Class 2 is regularly used on runways and taxiways in France.

EME specifications have no requirements for the layer surface texture as it is not used as a wearing course in France¹.

Best practice in Europe suggests the following precautions:

- EME should not be used as surface or binder layer since:
 - It may be prone to thermal cracking; and
 - It may not provide a surface texture with sufficient skid resistance
- Where multiple lifts of EME are constructed it is crucially important that good bonding between the two courses is achieved; and
- EME is sensitive to “under-design”.

¹ French practice differentiates between 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.

7. Design of EME

7.1 Principles

The underlying principle of designing EME base layers is to provide an extremely stiff asphalt layer derived mainly from the properties of a hard binder. While the use of hard grade bitumen, in conjunction with suitable aggregate gradings, will inherently be resistant to permanent deformation, adequate resistance to fatigue failure is ensured by a relatively high binder content.

7.2 Process

The design process for EME mixes is shown in Figure 1. Briefly the steps are as follows:

1. Select appropriate mix components in terms of aggregate and binder;
2. A suitable grading is developed from the different aggregate fractions;
3. The binder content is determined based on a minimum richness modulus, similar to the film thickness conventionally used in SA;
4. Using a trial mix design, specimens are compacted in a gyratory compactor. A maximum allowable air void content after a set number of gyrations has to be met. This is the first of the performance criteria, aimed at creating a workable mix;
5. Once workability criteria have been met specimens are subjected to a durability test;
6. Following satisfactory durability, the following structural performance criteria are assessed:
 - (a) Minimum dynamic modulus;
 - (b) Minimum level of resistance to permanent deformation; and
 - (c) Minimum fatigue life.

The various steps in the process are discussed in more detail in the following sections.

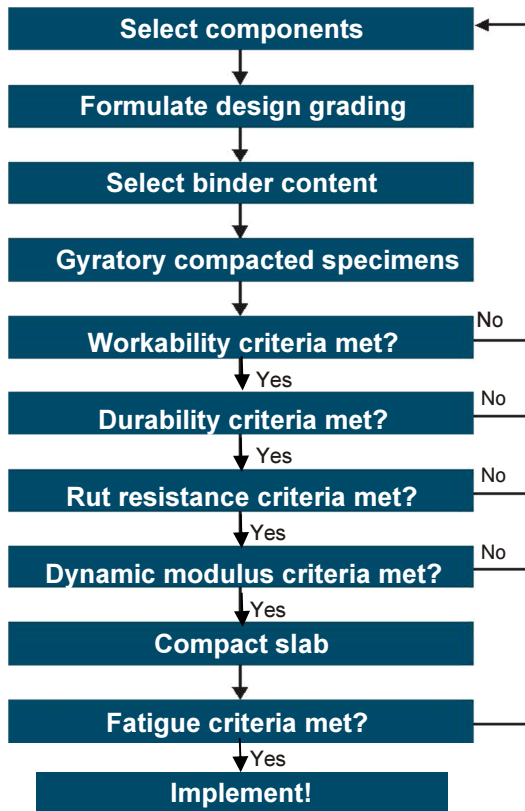


Figure 1: The design process

8. Selection of Materials

8.1 Constituents

8.1.1 Aggregates

Aggregates should be fully crushed, fractured stones. 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) to ensure the accommodation of a sufficiently high binder content.

The aggregate selection guidelines are shown in Table 1. The criteria are similar to those conventionally recommended for asphalt mixes.

The particle index test provides a measure of aggregate angularity and surface texture. The particle index compliance limit is provisional. Generally aggregates with a high particle index result in a higher VMA.

Table 1: Aggregate selection criteria

Property	Test	Method	Criteria
Hardness	Fines aggregate crushing test: 10% FACT	SANS 3001-AG10	≥ 160 kN
	Aggregate crushing value ACV		$\leq 25\%$
Particle shape and texture	Percentage of fully crushed coarse aggregate (> 5 mm)		100%
	Flakiness index test	SANS 3001 - AG4	≤ 25
	Particle index test	ASTM D3398	> 15
Water absorption	Coarse aggregate (>4,75 mm)	SANS 3001 - AG20	$\leq 1,0\%$
	Fine aggregate	SANS 3001 -AG21	$\leq 1,5\%$
Cleanliness	Sand equivalency test	SANS 3001 –AG5	≥ 50

8.1.2 Filler

As with conventional asphalt, filler is defined as the material passing the 0,075 mm (or 75 μ m) sieve. Table 2 shows the various types of filler in general use with the most important considerations to be taken into account of each type.

In EME, fillers are primarily used to meet the grading targets. When active fillers such as cement and hydrated lime are used, care should be taken not to increase the viscosity of the hot mastic beyond values that will affect workability during mixing and paving. *Where hydrated lime is used the quantity should be limited to 1% by mass of the total aggregate.*

Table 2: Filler types and properties

Filler type/origin	Considerations
Hydrated lime (active filler)	Improves adhesion between binder and aggregate; Improves mix durability by retarding oxidative hardening of the binder; Low bulk density and high surface area; Relatively high cost.
Portland cement (active filler)	Relatively high cost material; Effect on stiffness may reduce compactability.
Baghouse fines	Variable characteristics; More control required; Some source types may affect mix durability; Some types may render mixes sensitive to small variations in binder content.
Limestone dust	Generally manufactured under controlled conditions and comply with set grading requirements; More cost-effective than active filler; Although it is seen as inert filler the high pH reduces moisture susceptibility.

8.1.3 Binder

Typically either a 10/20 or a 15/25 penetration grade binder conforming to SANS 4001-BT1:2014 is used in EME. Table 3 shows the requirements for these hard paving grade binders.

Table 3: Requirements for hard pavement grade binders

Property	Test method	Unit	Penetration grade	
			10/20	15/25
Penetration at 25°C	EN 1426	0,1 mm	10-20	15-25
Softening point	ASTM D36 ²	°C	58-78	55-71
Viscosity at 60°C, minimum	ASTM D4402 ³	Pa.s	700	550
Viscosity at 135°C, minimum	ASTM D4402 ²	mPa.s	750	650
Flash Point, minimum	ASTM D92	°C	245	235
After RTFOT:	ASTM D2872			
Mass change, maximum	ASTM D2872	%	-	0,5
Softening point (ring and ball), minimum	ASTM D36 ⁴	°C	-	57
Increase in softening point, maximum	ASTM D36 ¹	°C	10	8
Retained penetration, minimum	EN 1426	% of original	-	55

² Using a shouldered ring

³ Recommended apparatus is the RV viscometer, using SC4 spindles with thermosel system,

⁴ Using a shouldered ring

8.2 Design grading

8.2.1 Recommended gradings

The LCPC design guide for bituminous mixtures provides target gradings for EME mixes. It should however be noted that **these gradings only provide a point of departure for the mix design process and should not be used to impose a restriction on the gradings adopted** for optimal mix designs. Until such time as more experience is gained, it is recommended that the envelopes published in the LCPC guideline be used as a guide.

The grading guidelines for EME base course are shown in Table 4 for SA standard sieve sizes in accordance with SANS 3001. For key sieve sizes, the table provides a target grading that can be used as a starting point, and also proposes typical grading envelopes. The values for the 14 mm nominal maximum size aggregate are plotted in Figure 2 for illustration purposes. Also shown is the maximum density line (assuming a 5% binder content). The suggested target grading is fairly close to the maximum density line for the smaller sieves. The grading includes a kink due to the relatively large percentage retained on and above the 5 mm sieve.

Table 4: Target grading curves and envelopes for EME base course

Percent Passing Sieve size	NMPS = 10			NMPS = 14			NMPS = 20		
	min.	target	max.	min.	target	max.	min.	target	max.
7,1 mm	48	56	68	53	56	73	47	55	66
5,0 mm		53		44	50	64	42	50	62
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	6,9	7,9

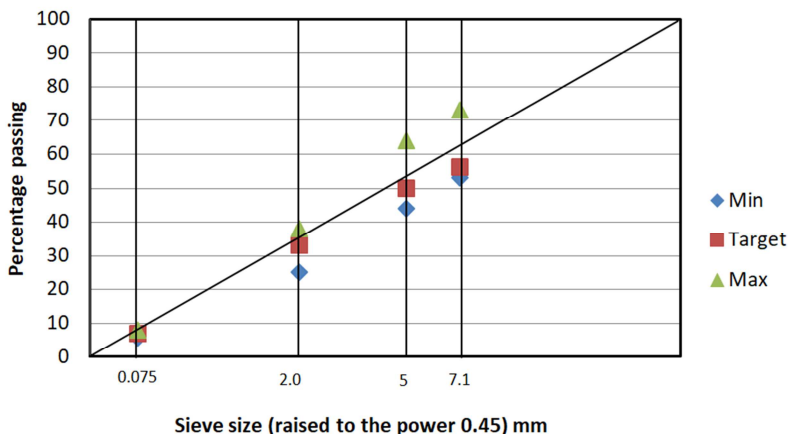


Figure 2: Illustration of typical grading guidelines for NMPS 14 mm

8.2.2 Lift thickness and maximum aggregate size

Since EME is a principal structural layer, it is critical that the specified overall layer thickness – and, hence, the adopted lift thicknesses – is met during construction. It should be noted that, in general, layer thicknesses of EME are less than those specified for conventional asphalt bases. This can be ascribed to the fact that the stiffness of EME layers is typically significantly higher than that of conventional asphalt bases thus requiring less depth for equivalent structural value. To achieve this superior structural performance, the achievement of the minimum layer depth is crucially important. EME is also richer in binder which, compared to conventional base courses, offers superior resistance to fatigue cracking

Another important consideration is that a well-designed and compacted EME layer or has low permeability, enabling it to be surfaced with a relatively-thin asphalt mix, bearing in mind that in areas of extreme temperature variation, sufficient insulation should be provided to prevent thermal cracking of the base.

While the EME layer thickness of a pavement is determined during the pavement structural design process, the construction of the layer may, for practical reasons, be carried out in more

than one lift. This will depend on a number of factors such as:

1. Compaction equipment employed to achieve the desired densification of EME
2. The superior heat retention of thicker lifts to extend the compaction window
3. The need for adequate cooling of the lift prior to:
 - a. opening to traffic in situations where traffic needs to be accommodated on newly constructed asphalt, or
 - b. subsequent lift construction

The maximum aggregate particle size is a fundamental property of the aggregate component of the mix and should be selected with due consideration of the intended asphalt layer or lift thickness. To ensure compactability of the mix and to counter segregation of the mix during handling and paving, the NMPS of the aggregate in a particular lift should be limited so as to have a value *less than a third of the thickness of the layer or lift being constructed*.

Guidance on the selection of aggregate NMPS in relation to the layer and lift thickness is given in Table A.1 in section A.2.6 of Appendix A: *Construction of EME*

8.2.3 Binder content

In the French asphalt mix design method binder content is expressed as a Richness Modulus, K deemed to be an important design parameter; consequently the **values in Table 5 should be strictly adhered to**.

This richness modulus is a measure of the thickness of the binder film surrounding the aggregate, and is related to the specific surface area and the density of the aggregate. The determination of K involves calculating the specific surface area of the aggregate grading of the mix based on particular sieve sizes.

The value of K is obtained from:

$$K = \frac{B_{ppc}}{\alpha \times \sqrt[5]{\Sigma}}$$

Where:

$Bppc$ = the mass of binder expressed as a percentage of the total dry mass of aggregate, including filler. (Note that this expression is different from the conventional expression of binder content used in SA)

Σ = specific surface area of aggregate given by:

$$\Sigma = 0,25G + 2,3S + 12s + 150f$$

and

G = Proportion* by mass of aggregate over 6,3 mm

S = Proportion* by mass of aggregate between 6,3 mm and 0,250 mm

s = Proportion* by mass of aggregate between 0,250 mm and 0,063 mm

f = Proportion* by mass of aggregate smaller than 0,063 mm

$\alpha = 2,65/r$ - a correction coefficient taking into account the density of aggregate with r being the relative density of the aggregate used in the mix design.

* The proportion of aggregate must be expressed as decimal fractions of the total mass i.e. if there is 38% of the mass passing the 6,3 mm and retained on the 0,250 mm sieves the value of S would be 0,38.

Table 5: Richness Modulus requirements

Richness modulus K	EME Class	
	Class 1	Class 2
	$\geq 2,5$	$\geq 3,4$

Note: The expression used to represent the proportion of binder in the mix used in the calculation of Richness Modulus is distinct from the more conventional expression generally used in asphalt design and quality control. Whereas the expression $Bppc$ represents the mass ratio of binder to dry aggregate, conventional binder content, B , represents the mass ratio of the binder to the total mix (i.e. binder plus aggregate)

To derive binder content B from B_{pcc} (e.g. for quality control purposes) use:

$$B \text{ (percent)} = \frac{100 \cdot B_{pcc}}{100 + B_{pcc}}$$

Example

For a B_{pcc} value of 6.05%

$$B = \frac{100 \times 6.05}{100 + 6.05}$$

$$B = 5.7 \%$$

8.2.4 Workability

Workability is assessed by monitoring the effort required to compact the material in the gyratory compactor. Replication studies were conducted by the CSIR taking into account the difference of gyratory angles employed in the European gyratory compactor (EN-12697-1) and the ASTM D6926 configuration in general use in SA, but both standards prescribing a rate of 30 gyrations per minute and a compaction pressure of 600 kPa. On this basis a compactive effort of 45 gyrations for apparatus complying with ASTM D6926 is proposed to determine the maximum allowable air voids as indicated in Table 6.

Table 6: Workability requirements

Test	No. of specimens	Method	Requirements	
			Class 1	Class 2
Gyratory compactor Air voids after 45 gyrations	3	ASTM D6926	≤ 10%	≤ 6%

8.2.5 Durability

In France durability of EME is assessed using an unconfined compressive test (EN 12697-12) on moisture conditioned specimens generally known as the Duriez test.

Local experience with the performance criteria indicated that it was

unnecessary to develop separate durability criteria for EME, hence the modified Lottman test in accordance with ASTM D4867 is proposed for this purpose.

The Modified Lottman test relies on indirect tensile strength measurements taken before and after conditioning by freeze-thaw cycles. Six samples of the asphalt mix are compacted to within a void content range of 6 - 8% (or to target field voids) and partially saturated with water (saturation limit of between 55 and 80%). Three of the six specimens are frozen for at least 15 hours and subsequently immersed for 24 hours in a hot bath set at 60°C. These constitute the "conditioned samples".

All six samples are then brought to a constant temperature and their indirect tensile strengths determined.

The ratio of the indirect tensile strengths of the conditioned and unconditioned samples is referred to as the tensile strength ratio (TSR). It is recommended that the minimum requirement for TSR is 0,80 for all climates zones in SA.

8.2.6 Permanent deformation

The resistance against permanent deformation (rutting) of the EME is routinely assessed by means of the Hamburg Wheel Tracking Test (HWTT) as per AASHTO: T 324⁵ on two specimens for each binder content, all as described in Manual 35, except that the minimum number of wheel passes of 20,000, applicable to all climatic zones, are referred to 4 mm maximum rut depth for EME as indicated in Table 7.

Table 7: Requirements for resistance to permanent deformation

Test	No. of specimens	Method	Requirements	
			Class 1	Class 2
Hamburg Wheel Tracking Test	2 per binder content	AASHTO T324	≤ 4 mm rut at 20,000 repetitions	

⁵ While AASHTO: T 324 requires laboratory specimen conditioning according the AASHTO: R 30, specimens should be prepared in accordance with Sabita Testing Protocol ASP 4.

8.2.7 Dynamic modulus

A key performance characteristic of EME is the dynamic modulus of the layer. This property of the material is determined using the AASHTO TP 62 test standard, which also forms an integral part of the revision of the SA Pavement Design Method.

Following further comparative testing on mixes in South Africa and France, since the publication of the first (2013) edition of this manual, the minimum modulus required for EME, as determined on three specimens, is 16 GPa at a temperature of 15°C and a loading frequency of 10 Hz.

8.2.8 Fatigue

While in the French design method fatigue tests are performed on trapezoidal specimens, a four point bending (FPB) fatigue test on beam specimens is proposed. Following further work carried out by the CSIR in 2015 the minimum requirements as listed in Table 8 have been adopted.

Table 8: Requirements for fatigue resistance

Test	No. of specimens	Method	Requirements	
			Class 1	Class 2
Beam fatigue test at 10 Hz, 10°C,	9	AASHTO T321 - 14 ⁶	≥ 10 ⁶ reps @ 210 µε	≥ 10 ⁶ reps @ 260 µε

⁶ In this 2014 version of the test standard the failure point, or fatigue life, of the specimen is defined in clause 3.1.1 of that standard as the load cycle at which the specimen exhibits a 50 percent reduction in stiffness relative to its initial stiffness.

8.3 Summary of performance requirements

Property	Test	No. of Specimens	Method	Requirements	
				EME Class	
				Class 1	Class 2
Workability	Gyratory compactor, air voids after 45 gyrations	3	ASTM D6925	≤ 10%	≤ 6%
Durability	Modified Lottman, TSR	6	ASTM D4867M	≥ 0,80	
Resistance to permanent deformation	Hamburg Wheel Tracking Test	2 per binder content	AASHTO T 324	≤ 4 mm rut at 20,000 passes	
Dynamic modulus	Dynamic modulus at 10Hz, 15°C	3	AASHTO TP62	≥ 16 GPa	
Fatigue (see footnote 6 above)	Beam fatigue test at 10 Hz, 10°C	9	AASHTO T321	≥ 10 ⁶ reps @ 210 με	≥ 10 ⁶ reps @ 260 με

9. Structural design

Clearly, as EME bases are likely to be used under conditions of intense traffic on major routes, the use of analytical methods of design, e.g. mechanistic-empirical procedures are justified – if not a prerequisite – to estimate key stresses and strains at critical zones to come to reasonable conclusions as to the carrying capacity of such pavements.

Multi-layer linear elastic analysis routines can be used to calculate the stress-strain states within the pavement system which can then be employed to calculate the bearing capacities of the individual layers and the pavement system.

The critical points where stress-strain conditions are normally computed vary for different material types as follows:

- **Asphalt layers:** The horizontal tensile strain at the bottom of the layer controls the fatigue life of the layer;
- **Cemented layers:** The horizontal tensile strain at the bottom of the layer controls the effective fatigue life of the layer, while the vertical compressive stress at the top of the layer controls the crushing life;
- **Granular layers:** The major and minor principal stresses at the middle of the layer controls the shear stress potential of the layer; and
- **Soil (subgrade) layers:** The vertical compressive strain at the top of the layer controls the rutting life of the subgrade.

9.1 Analysis of Pavement Structures

9.1.1 Climatic conditions

The pavement temperature conditions can be estimated using CSIR ThermalPADS software, which provides reasonable predictions of pavement temperatures, based on historic air temperature data. For pavement analysis three design temperatures are commonly determined:

- The average annual minimum surface temperature, which represents the worst case for fatigue distress;
- The maximum seven day average temperature at the depth of 20 mm in the pavement (SUPERPAVE method), representing the worst case for permanent deformation during the hottest

- week of the year; and
- The average annual pavement temperature.

9.1.2 Traffic loading

Traffic loading inputs such as a dual wheel load system of 20 kN per wheel, at 350 mm spacing and a tyre inflation pressure of 800 kPa are typically used. Accordingly, an average contact stress on the pavement can be determined based on stress-in-motion studies. For instance a tyre inflation pressure of 800 kPa may translate to an average contact pressure of 650 kPa.

Loading frequency, which is required for the design of asphalt layers, can be determined from the following parameters:

- Average speed of trucks;
- Contact radius, based on the equivalent uniform contact stress derived from the assumed tyre inflation pressure;
- Travelled distance during loading time;
- Load duration and, hence, loading frequency.

9.1.3 Pavement stiffness values

Existing substrate

The stiffness values of existing layers, to be incorporated into the pavement structure, can be assessed using FWD analysis and back-calculation software such as the CSIR backGAMES.

EME layer

It is recommended that the dynamic modulus for structural design purposes be evaluated by generating master curves. Such a procedure would allow for sensitivity analyses covering an appropriate range of test temperatures related to the specific environment and loading frequencies estimated for the specific traffic conditions.

9.2 Damage modelling

9.2.1 Fatigue

Following an extensive investigation into the fatigue properties of EME layers placed on South African projects and LTPP trial sections as well as international data published by Austroads, revised transfer functions

of the S-N type were developed. It is proposed that, for the time being, the following provisional transfer function be used as an improvement to adopting current transfer functions for conventional asphalt bases.

$$\log(\mu\epsilon) = -0,1782(\log \text{cycles}) + 3,5028$$

Figure 3 provides a comparison between the transfer functions for conventional asphalt base and those proposed for EME, indicating a higher expected fatigue life for EME. The ratio of the expected fatigue life of EME to that of conventional asphalt base for similar strain levels ranges from 17 (1000 $\mu\epsilon$) to 130 (100 $\mu\epsilon$).

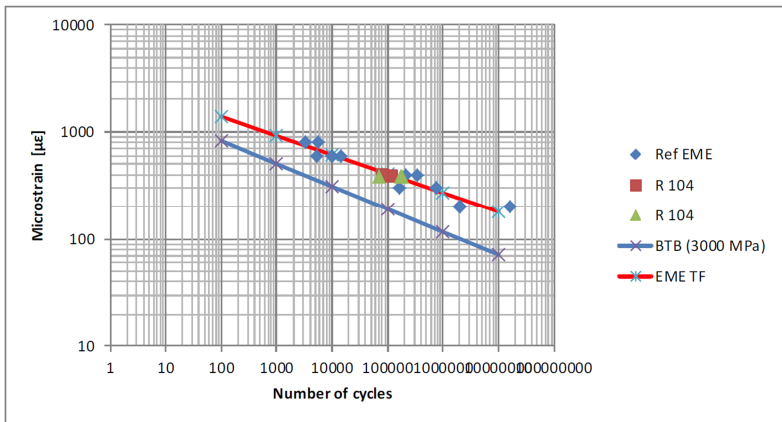


Figure 3: Comparative fatigue performance of EME and conventional HMA

9.2.2 Permanent deformation

A reasonable estimate of the permanent deformation behaviour of an EME layer can be made by using the models in the Mechanistic Empirical Pavement Design Guide – MEPDG – (NCHRP 1-37A), recently introduced in the USA. Recent work in South Africa indicates that they may be suitable to some extent. The MEPDG model uses the vertical strain (EZZ) at the centre of the layer below the centre of the tyre as the main predictor of permanent deformation.

The final calibrated model for laboratory and field data for the relationship between elastic and plastic strain in MEPDG is:

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

Where:

ε_p = the accumulated plastic strain

ε_r = the resilient strain at the middle of the layer

T = temperature (°F),

N = the number of load repetitions

\hat{N}_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.

$$k_1 = (C_1 + C_2 * depth) * 0.328196^{depth}$$

$$C_1 = -0.1039 * h_{ac}^2 + 2.4868 * h_{ac} - 17.342$$

$$C_2 = -0.172 * h_{ac}^2 + 1.7331 * h_{ac} + 27.428$$

Figure 4 shows the calculated permanent deformation plotted against the number of load repetitions for an 80 mm thick layer calculated during the design of the trial sections in eThekweni. The calculated plastic strain was multiplied by the layer thickness to obtain the deformation of the layer.

The model predicts that the critical level of 20 mm rut will be reached after 125 million standard load repetitions.

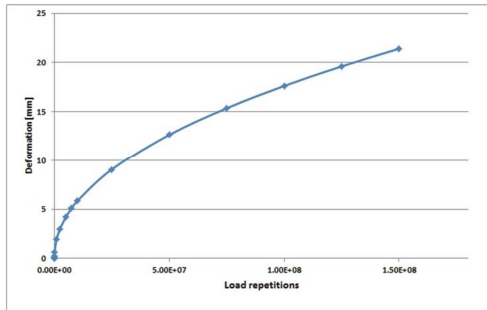


Figure 4: Calculated permanent deformation

10. Construction

It is important that sound construction practice is adhered to during the placing of EME layers, to provide reasonable assurance that the pavement layer(s) will perform as expected.

A comprehensive set of guidelines covering the following aspects are included as Appendix A:

- Storing, manufacturing, transporting and preparation
- Joints
- Paving
- Compaction
- Sampling
- Quality

Users of this product should note the following characteristics of EME:

- During compaction this material characteristically “stiffens up” quite suddenly mainly as a result of the relatively high binder viscosity associated with the cooling of the mat. Once this occurs, further rolling has very little effect on compaction;
- EME, being designed as a binder-rich, low permeability mixture can be expected to have a rich finish on completion of compaction.

11. Use of RA in EME

The use of RA in asphalt mixes in South Africa is well documented and described in detail in Sabita Manual 36 / TRH 21: *Use of Reclaimed Asphalt in the Production of Asphalt*, covering the sourcing, processing, testing of RA and will not be repeated in this document.

Special attention should however be given to the RA binder properties to ensure that the combined virgin and RA binder complies with the 10/20 penetration grade used to produce EME. This is especially the case when locally manufactured 10/20 is used, as historic data of these binders indicate that their penetration values are marginally high and often just falls within the maximum value of 20.

Table 9 below is a blending chart for 10/20 penetration grade binder and can be used to ensure that the blended RA and virgin binder meets the penetration requirements.

In the event that the RA binder has recovered properties “softer” than the 10/20 penetration grade, the EME asphalt mix may have difficulty in meeting the required specified stiffness and will limit the amount of RA that can be successfully incorporated in the EME mix. RA binders that contain polymers could improve the fatigue properties of the EME mix, but in such cases excessively high RA binder replacement percentages could lead to lower stiffness of the EME mix.

Table 9: Binder blending chart for a 10/20 penetration grade binder

RA binder replacement (%)	Recovered RA binder penetration (dmm)						
	5	10	15	20	25	30	35
30	12	15	17	19	20	21	22
25	13	16	17	18	20	20	21
20	14	16	17	18	19	20	21
15	15	16	18	18	19	19	20
10	16	17	18	18	19	19	19
5	17	17	18	18	18	18	19
0	18	18	18	18	18	18	18
Resultant penetration of 10/20 penetration grade bitumen and RA binder blend							

12. Bibliography

- Sabita - *High modulus asphalt: Assessment of viability based on outcomes of overseas fact finding mission, 2008;*
- Sabita - *Interim guide for the design of high modulus asphalt mixes, Denneman and Nkgapele CSIR BE, November 2011;*
- CSIR BE - *HiMA Evaluation On Road R80 In Gauteng, June 2007;*
- CAPSA'11 - *Transfer of High Modulus Asphalt Technology to South Africa, Denneman et al;*
- Sabita Digest 2011 *High modulus asphalt technology transfer successfully completed, Denneman;*
- TRL *Report TRL 636 The application of Enrobé à Module Élevé in flexible pavements, Sanders and Nunn, 2005;*
- Sabita *Implementation of High Modulus Asphalt technology at South Coast Road, eThekweni, Denneman, Nkgapele, Komba;*
- Sabita *High Modulus Asphalt Technology Transfer, Final Report, Phase 2, Denneman et al*
- Sabita *EME Thickness design evaluation, WJvdM Steyn January 2014*
- Sabita *EME Transfer function, WJvdM Steyn January 2015*
- Austrroads *Technical Report AP-T283-14: High Modulus High Fatigue Resistance Asphalt (EME2) Technology Transfer*

Appendix A: Construction of EME

Introduction

It must be recognised that EME is a type of asphalt differentiated only by its harder binder, when compared to other asphalt types. The design checks and procedures in this guideline should be followed to ensure proper construction of EME. Sound practices must be adhered to during the batching, transporting and placing of EME layers to provide reasonable assurance that the material will perform as expected.

This chapter is not intended to simply repeat what is already in the public domain, but instead to add hints and pointers gleaned from specialists in the field, as well as to highlight salient points in other publications which would relate to the production and paving of EME.

Section 4200 of the COLTO Standard Specifications, Chapters 12 and 13 of the South African Pavement Engineering Manual and various Sabita, TRH and TMH manuals all provide valuable information regarding the construction of any asphalt layer, including EME.

The section covers the work relating to:

- The manufacture, storing and transporting of the EME to the site;
- Preparation of the underlying layer;
- The paving operation; and
- Sampling and testing.

Requirements which are common to all asphalt types are not specifically covered. The reader is referred to standard specifications and other relevant publications in this regard.

A.1 Storing, manufacturing, transporting and preparation

A.1.1 Storing

a) *Quality*

A Quality Management Plan and daily checklist must be made available always by the asphalt manufacturer. These will include details of:

- Stockpiling and separating the aggregates into their various fractions;
- Storage of the binder and any additives to be used;
- Tests and testing frequencies;
- Action to be taken if there is a change in the aggregate properties; and
- The assurance that the correct mix is delivered to site.

b) *Method statement*

In addition to the above, a Method Statement must be drawn up by the asphalt manufacturer specifically for the manufacture, storing and transporting of the EME to the site.

c) *Aggregate stockpiles*

The recommended sampling frequency for grading and flakiness index on the various aggregate components is given as at least one test per 400 tons. However, for many quarries, the crusher dust is essentially an end-product and so this aggregate fraction needs to be carefully monitored.



TMH 5 Sampling Method MB1

d) Bituminous binders

Every tanker load of bitumen must be accompanied by a certificate of compliance from the manufacturer as per Table 3 of this manual.

A.1.2 Manufacturing

a) Reclaimed asphalt (RA)

If RA is used in the mix, there must be a processing, crushing and screening system in place, as given in Chapter 7.2.3 of TRH 21. Uniformity is of prime importance and the gradings and residual binder properties must be regularly checked.

Prior to the RA entering the mixer, the stockpile needs to be properly loosened up to ensure that there is no “nesting” of chunks of RA in the mix and that it is evenly spread through the mix.



Chapter 7.2.3 of TRH 21

b) Temperature



Ambient Temperature

No paving may be carried out if the ambient temperature is falling below 6°C.

The target mixing temperature of EME should be $170^{\circ}\text{C} \pm 5^{\circ}\text{C}$. Thermometers must provide accurate measurements and must therefore be calibrated regularly. If necessary, the “Spot Test” can be carried out to determine if the bitumen has been burned.



Spot Test

A small drop of bitumen is dropped onto a filter paper. If the spot formed is uniformly brown, then the test is negative. If the spot formed is brown with a black centre, then the test is positive.

In view of the high temperatures related to EME, safety requirements must be rigorously adhered to, both at the plant and on site.

A.1.3 Transporting

a) Asphalt trucks

Truck bins must be inspected at the start of each shift, to ensure that they are clean and sponged or sprayed down with release fluid to stop the asphalt from sticking to the sides and that the tailgates are secure and closed properly. The trucks should preferably not be used for any other purpose than for carting asphalt.



Release Fluid

No engine oil, diesel or paraffin may be used as a release fluid.



Thermal Blankets

Thermal blankets - not canvas covers - must be used always.

b) Communication

It is of the utmost importance that there is constant communication between the asphalt plant and the site, so that either the manufacturing or the paving rate can be adjusted if there are delays at either end. The person in charge of the paving team must estimate at what time the trucks are required to arrive on site, so that they don't end up standing for hours cooling down, and that the rate of supply is commensurate with the paving speed.

c) Delivery to site

The time between batching and tipping should be planned to ensure that the trucks are tipped in the same order as they are batched.

To ensure that the paver does not have to stop unnecessarily, the asphalt should be delivered to site at a similar rate to which is being paved.

d) Weighbridge tickets

Weighbridge tickets must show the date, time of batching, asphalt type, tonnage, cumulative tonnage and batch temperature. The person receiving the tickets on site must be able to fully understand the contents on the ticket, as well as what the required mix is. Every ticket must be checked to ensure that the correct, EME, mix has been delivered.

A.1.4 Preparation

a) *Weather conditions*

In view of the significant effect of weather conditions on the paving operations, care must be taken to check for imminent rain, cold temperature conditions and wind. A very low ambient temperature can significantly reduce the window period for achieving compaction, especially if the new layer is to butt against an existing cold layer.



Full-width compaction (see Section 5.4.1(b))

Compaction across the full width of the paved area is crucial. Long before the start of the paving, the contractor, together with the resident engineer, must study the drawings and inspect the road to be paved, to check if there are any obstacles or potential obstacles in the way of the rollers. If necessary, there may have to be design changes to items such as concrete barriers, kerbs or other adjacent structures, to ensure that there is compaction right up to the edges. Alternatively, the construction programme may have to be altered so that these structures are built at a later stage.

If both sides of an existing dual carriageway are to be paved, transporting to the opposite carriageway will require that the trucks continue to the next interchange before turning around. This can use up valuable time, especially in winter, causing the mix to cool and a crust to form. If feasible, the furthest ends should be paved when it's warmer and the shorter distances kept for the colder periods.



Laser guns

Calibrated laser guns are at best an indication of the temperature and cannot be used to reject a mix.

b) Preparation for paving

The full length of road to be paved must be carefully inspected and the substrate checked for visual defects to ensure a clean, hard and level surface. Special care should be given to joints and there must be sufficient space for the compaction equipment on the outside edges next to structures.

c) Plant trial

The latest edition of TRH 8 (SABITA Manual 35) must be consulted when carrying out the design and plant trial of the EME. It is noted that D3 Asphalt Mix Design form has been updated to include for the incorporation of PG Grading and the Bailey Method of aggregate packing. TRH8 allows for 3 asphalt mix design levels, the design of EME being at Level III and thus dependent on performance related laboratory testing. Between 8 and 12 weeks should be allowed for the design mix process.

Once a successful plant trial, consisting of a 0.5% tolerance, has been carried out, the trial section can be paved.

d) Paving trial

A paving trial is essential for demonstrating that the asphalt plant can produce a consistent mix as per the agreed design, that the transportation proceeds smoothly, that the paving crew is experienced and capable of paving to specification and that all plant is

reliable and in good condition. Any problems relating to the construction, and constructability of the layer, which arise must be immediately rectified. A high level of monitoring, including photographic records, visual assessments and data recording and testing will be required to ensure that the process can be replicated to meet the project specification. Once the paving trial has been approved, there must be no deviations from the procedures or changes in plant, unless there is full agreement from the employer and/or the engineer. A paving trial flow chart is presented below.

The 3-page Check List given in Chapter 12, Section 4 of SAPEM **must** be completed by the engineer, together with the contractor, at the paving trial. A copy is included at the end of this Chapter. Any deviations are to be corrected and if there is doubt regarding any aspect of the trial, a fresh trial may be called for. Check 1: Paver, as well as Checks 9 to 12 relating to the rollers, hand tools and haulage vehicles, must be used for each day's production and signed off by the contractor and the engineer's representative.



Objectives of a paving trial

- Determine mix cooling curve from plant from the time it leaves the silo to commencement of rolling
- Determine haul time
- Determine mix drainage susceptibility during storage, transportation and transfer into hopper
- Determine mix segregation during transportation
- Determine mix segregation susceptibility during transfer
- Determine mix segregation susceptibility during paving
- Determine mix workability through the screed
- Determine mat tenderness during rolling
- Determine paving speed
- Determine rolling pattern
- Determine screed and tamper compaction
- Determine optimum planning angle
- Determine lift consolidation factor
- Determine optimum temperature to commence rolling
- Determine compaction effort density relationship
- Determine compaction window
- Determine mat cooling curve from the time the mat is laid until it reaches 30 degrees.
- Determine the joint cutting technique
- Determine the joint paving technique
- Determine the joint finishing technique
- Determine mat trafficking time
- To finalise the compilation a paving plan
- To finalise the compilation a communication plan
- Test and update the tender method statement.
- Test and update the works supervising / project engineers method statement

When do you do a paving trial?

- A separate paving trial must be done for every newly designed mix.
- Should any of the variables change appreciably within the same project from what was accepted at paving trial stage, then a new paving trial must be undertaken.

Where should you do a paving trial?

- The location of a trial should be representative of the typical site conditions (permanent works).
- Should there be extremes from the typical site conditions, it is recommended that successful paving trials also be undertaken under those conditions (i.e. longitudinal grades).
- The trial location must allow for the construction of both longitudinal and transverse joints.

Objectives of a paving trial?

- A paving trial has many objectives that work together to ensure a high-quality end product.

Inspection and acceptance of plant and personnel

- Applicable legislated requirements are to always be met at minimum for both plant and personnel.
- The proposed asphalt transportation, construction and quality management team must be presented to the client for consideration and acceptance.
- Minimum recommended documentation are certificates of appropriate experience, competency and qualifications.

How to do a paving trial?

- Start with planning the trial
- Convene plant mix analysis meeting
- Convene a technical meeting for specification clarification meeting with the entire team that will be involved in the trial

Planning a paving trial

- In planning a paving trial all variables that will impact on the final mat produced will need to be taken into consideration.

Inspection and acceptance of support layer

- The supporting layers contractor, where new, is to confirm that the layer meets specification.
- The asphalt contractor shall inspect the support layer to satisfy himself that the layer is acceptable for construction of the asphalt layers as specified.
- Where the works is being done on an existing road, the asphalt contractor shall inspect the road to satisfy himself the road is acceptable for the construction of the asphalt layers as specified inclusive of as-builts and process control data.

Plan to meet trial objectives

- At least 2 weeks prior to intending to commence with the paving trial, the asphalt contractor shall submit to the client a detailed plan of how he will meet the objectives of the paving trial in Objectives of a paving trial
- This key meeting must also explain the objectives of the trial as well as roles and responsibilities of all during the trial
- The meeting must also assign those roles and responsibilities and record of such must be kept by the client.

Team involvement

- In instances where the project includes works supervision by project engineers, they would also prepare a detailed plan on how they will contribute as well ensure that the objectives are met.

Post paving analysis

- The records and observations from the paving operation shall be collated by the asphalt contractor, analyzed, then reported.
- This shall also include routine paved layer testing data as well as mix analysis data.
- Should it be concluded that the paving trial was a success, then the "Determinations" shall be recorded as the point of minimum compliance for quality achievement with the contractor complying at minimum with the "Determinations".

End of paving day

- The asphalt contractor (and project engineers) shall include in his plan to meet the objectives his end of paving day actions.

During the trial

- The assigned shall keep record as per meeting of objectives plan.
- Changes from the "Meeting Objectives Plan" shall be recorded with reasons for same.
- Quality management shall follow the specified quality management scheme in addition to any measures laid out in the "Meeting the Objectives" Plan.

Acceptance

- Further, should it be concluded that the trial is a success, then the client may consider the mix as well as the other proposals (as concluded in the preceding trial's) for asphalt works, for acceptance.

A.1.5 Further reading

SAPeM Chapter 12:

- Section 2.1: Crushed stone plant;
- Section 2.2: Asphalt production plants.

SAPeM Chapter 13:

- Section 6.4: Tests for acceptance control.
- Section 6.5: Acceptance testing of the asphalt mix.

TMH 5 – Sampling methods for road construction materials

TRH 21: Hot mix recycled asphalt – latest edition.

Sabita Manual 5 – Guidelines for the manufacture and construction of hot mix asphalt.

Sabita Manual 8 – Guidelines for the safe and responsible handling of bituminous products.

Sabita Manual 22 - Hot mix paving in adverse weather.

Sabita Manual 35 – Design of asphalt for roads.

A.2 Joints

A.2.1 Paving Adjacent to Existing EME

All joints shall be cut or milled in such a way that full compaction is achieved right into the corners. Longitudinal joints must be cut cleanly and squarely prior to paving the adjacent layer.

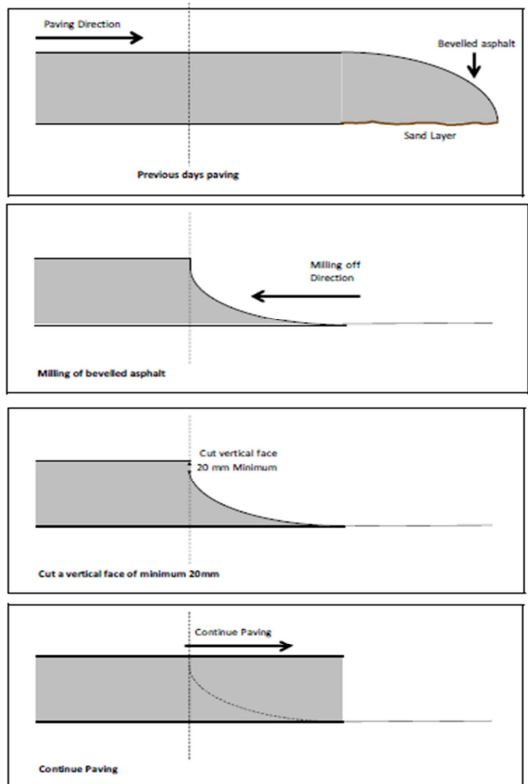


Getting compaction of the joints right

The most common weakness in any pavement is the lack of proper compaction of the joints.

A.2.2 Transverse Joints

Care must be taken to ensure that there is proper compaction right into the bottom corner of the transverse joints when in a box. Milling back into the new work gives a compactable curved face at the bottom. The top shall be cut vertically to 3 times the maximum stone size, to prevent feathering. The steps are shown on the adjacent sketches.





Cutting the joints

If space does not allow for the use of a milling machine, the joint must be cut while the mix is still fresh, since the alternatives would be to cut it with a diamond saw and use a jackhammer which is not recommended.

A.2.3 Longitudinal Joints

If paving more than one lifts against existing asphalt, the longitudinal joints of the top and bottom layers shall be offset by 150 mm as shown in the sketches on the following page. This will improve compaction by creating a lip for the roller operator to properly compact into the bottom corner, as well as lengthening the water path.

For winter paving, heaters can be attached to the edge of the paver to heat the joint and prevent excessive cooling down of the new layer.

A.2.4 Stages of Cutting Longitudinal Joints

EXISTING ROAD



Pinch method

During the construction of an asphalt mat against an existing layer, the pinch method is an appropriate measure to obtain compaction and create a uniform longitudinal joint. This process entails paving of the asphalt layer against the existing layer, however commencing rolling 100mm in from the longitudinal edge with the first pass. The 100mm uncompacted row is then “pinched” into the corner of the joint with the second pass. Thereafter, the normal compaction process will commence.

Mark out the section to be milled and paved - 150 mm wider than the final lane width.

Stage 1

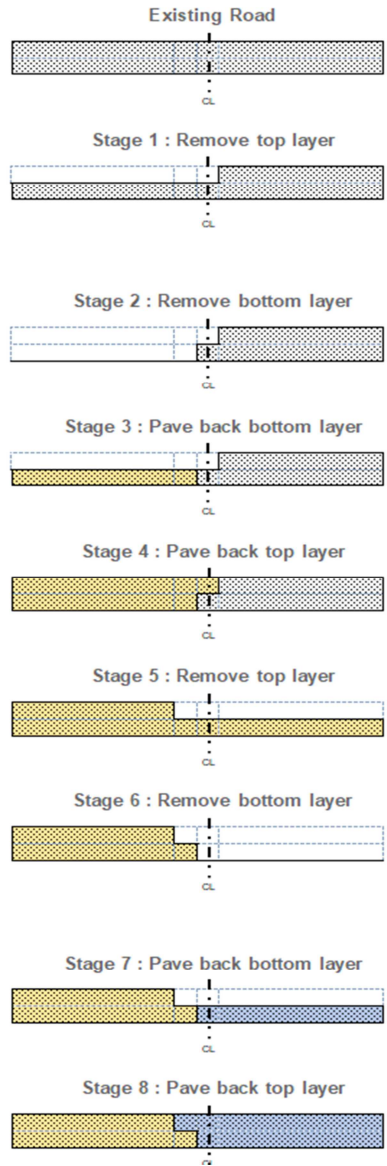
Mill down to half of the pavement depth and to the marked width, being 150 outside the final width. The selected milling depth must consider the maximum and minimum permissible paving thicknesses for the EME type to be paved back.

Stage 2

Mill down to the full depth of the layer, but 150 mm in from the first cut.

Stage 3

Pave back bottom lift and allow the rollers to ride on the available lip and performing the “pinch” method to ensure full compaction into the corner.



Stage 4

Pave back top lift to the full milled width, also using the “pinch” method to achieve compaction into the corner.

Stage 5

Mill down to half of the pavement depth, 150 mm the other side of the final width. This will entail milling out 300 mm of the newly paved top lift.

Stage 6

Mill down to the full depth of the layer, ensuring that the newly paved asphalt on the adjacent lane is exposed and that no old asphalt is left in place.

Stage 7

Pave back the bottom lift in the same manner as was carried out on the adjacent lane.

Stage 8

Pave back the top lift in the same manner as was carried out on the adjacent lane.

A.2.5 Positioning of longitudinal joints for new work



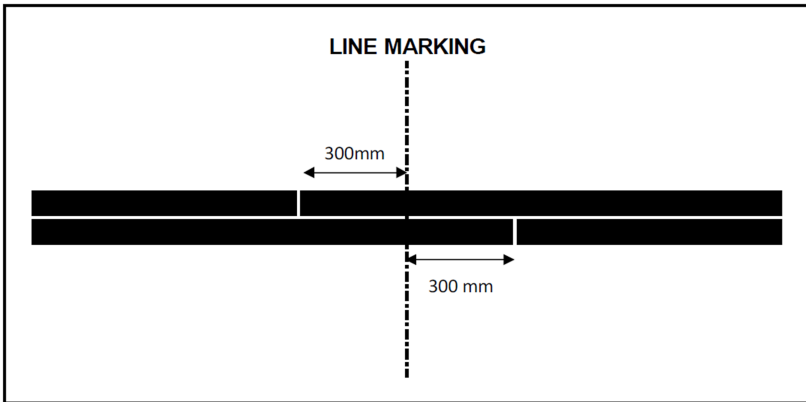
Spray-jet

If a spray-jet type of paver is used, the following must be observed:

- The spray jets must be checked constantly and blocked jets cleaned immediately.
- If any loose asphalt falls out of a truck in front of the paver, it must be cleaned off the road before the paver goes over it and the section re-tacked by hand if necessary.
- A dedicated sweeper shall be stationed in front of the paver to remove asphalt and loose stones and to warn the foreman of any problems.

Longitudinal joints should not coincide with the wheel paths and all joints between different EME lifts should be staggered and stepped. The bottom lift should extend 300 mm on one side of the centreline

and the second lift, 300 mm on the other side of the centreline and the surfacing joint on the centreline.



Multiple lift combinations

Whilst thick EME layers can be paved in multiple lifts utilising different stone sizes, cognisance of the following should be taken:

- Economic feasibility associated with the relatively high cost of two mix designs; and
- Practical engineering judgement should be applied when recommending lift thicknesses and stone sizes in two lift construction. Attention must be paid to the Nominal Minimum Particle Size (NMPS).

A.2.6 Specified layer thicknesses

Wherever possible, the layer thickness should be at the higher end of the tolerance to prevent ravelling of too-thin a layer. Table A.1 provides guidance on 2-lift combinations where necessary for different layer thicknesses. These combinations could be varied for practical purposes, provided that the minimum lift thickness is 50 mm. The recommended aggregate NMPS for each lift situation is also given.

There is no restriction to the number of lifts which may be paved on top of one another. However, the temperature inside a lift will be significantly higher than the measured surface temperature and thus if the road is to be opened to traffic on completion, or a subsequent lift needs to be constructed on top of the layer, the surface of the lower layer should be $\leq 30^{\circ}\text{C}$ to prevent flushing and rutting. (See section A.6.1 of this appendix.

Table A.1 Lift thickness and NMPS for layer construction

Layer thickness	Options	
	Lift thickness (mm)	NMPS (mm)
50	50	10, 14
60	60	10, 14
70	70	10, 14, 20
80	80	10, 14, 20
100	2 x 50	10, 14
110	2 x 55	10, 14
120	2 x 60	10, 14,
130	2 x 65	10, 14, 20
140	2 x 70	10, 14, 20
150	2 x 75	10, 14, 20
160	2 x 80	10, 14, 20

Please note, all options provided are limited to their respective maximum lift thicknesses



Single Lifts > 80mm

Lifts greater than 80mm have the following risks:

- Extended time required for cooling of layer prior to opening to traffic;
- High early traffic loading may result in deformation.

A.2.7 Tacking of joints

Both longitudinal and transverse joints shall be fully tacked to the same specification and to at least the specified spread rate for the base, to ensure a watertight bond.

A.2.8 Bitumen impregnated tape

Proprietary bitumen-impregnated tapes can provide a rich bitumen coating to seal the joint. This is particularly effective in winter and should be seriously considered when paving at temperatures below 15°C. However, if used they should be firmly attached to the edges of the layer to be paved against using a staple-gun and they must be constantly checked to ensure that they haven't become dislodged during the paving, especially by truck wheels being driven over them. This type of tape is not readily available and will need to be ordered.

A.2.9 Further reading

COLTO Section 4200 is in the process of being replaced by Chapter 9 of the COTO Standard Specifications for Road and Bridge Works for State Road Authorities.

SAPEM Chapter 12, Sections 3.9.1 Prime coats and 3.9.2.

A.3 Paving

A.3.1 Checks during Paving

All equipment shall be continually checked during paving, making use of the SAPEM trial pavement check sheets. There must be no oil leaks, the flights must be set and the heating plates on the paver must have reached the required temperature before starting.

If irregularities show up behind the screeds, the paver shall be stopped immediately and the fault rectified. Any defects in the mat shall be corrected immediately and before any rolling is carried out on it. The thickness of the loose mat shall be checked regularly across the full width.

If the temperature of the asphalt behind the paver is less than 165°C, the paving foreman shall take urgent steps to achieve compaction as soon as possible.



Areas of importance

A check list, as given in Table 13 in Chapter 12 of SAPEM (Page 127) must be drawn up and checked and signed off each day by the responsible persons from both the paving and contract administration teams.

Clear lines of communication must be maintained between the paving team and the batch plant.

At least 2 gyratory compaction tests must be carried out on each shift by the asphalt plant laboratory during the mixing process. If any change in the workability of the mix is noticed, the site shall be notified, so that the rolling pattern can be adjusted accordingly.

A.3.2 Paving equipment

The space between the auger and the edge of the spreader box must not exceed 200mm.

A Material Transfer Vehicle (MTV) will help in ensuring a consistent paving temperature and a constant paving speed. However, there can sometimes be a build-up of fines in the hopper which would intermittently drop onto the conveyor and transferred onto the road pavement. If this happens, the material is to be immediately removed and replaced with the proper mix.



Paving Crew

The Paving crew needs to show proof of competence; alternatively the paving crew needs to employ a consultant with knowledge and the ability to make sound engineering judgement.

A.3.3 Bond coat

This is an important aspect, which is often overlooked. The purpose of the bond coat is to assist in ensuring a proper bond between the lifts. A bond coat of 60% bitumen-emulsion at a rate of 0.3 to 0.5 litres/m² is applied, but other types and spread rates can be specified.

Reversing trucks onto the bond coat to tip, or the use of a MTV, can cause the bond coat to lift and thus create a loss of bond. In addition, if the adjacent layer has already been surfaced, the tyre tracks can create unsightly marks on it. The use of “non-tracking” bond coats should therefore be seriously considered. Applying the tack to the edges using a brush is more effective than by spraying and there is less likelihood of overspray onto the adjacent layer.



Non-Tracking Bond Coat

Non-tracking bond coat is an advanced asphalt emulsion tack specially formulated to dry extremely fast into a hard and driveable coating--often in less than 10 minutes.

A.3.4 Paving

If more than one lift is to be paved in the day's production, the lower lift must be allowed to cool down to a maximum temperature of 30°C before tacking and paving the next lift. As stated in section 5.2.6, if the road is to be opened to traffic, the temperature of the bottom lift should be $\leq 30^{\circ}\text{C}$ before paving the top lift, to prevent rutting of the still hot mix.

A.3.5 Further Reading

Sabita Manual 5 (latest edition): Guidelines for the manufacture and construction of hot mix

A.4 Compaction

A.4.1 Compaction Procedures

The thickness of the loose mat must be checked regularly across the full width, to ensure that the specified minimum layer or lift thickness is being achieved. A uniform paving pattern must be retained and the compaction checked using a nuclear gauge with the correct MTRD programmed in. Note that the nuclear gauge is only a process control indicator and an error of on average up to 1.5% can be expected. The calibration methods prescribed by the manufacturer must be followed to ensure that it is properly calibrated for the specific mix type.

It is recommended that no-one may walk on the uncompacted mat behind the paver before the rollers, since the footprints can be permanently embedded.

A.4.2 Achieving the specified maximum field voids

Thorough, uniform, compaction is necessary. The very low penetration binder is prone to stripping if moisture ingress occurs in the mix and it is therefore strongly recommended that voids should never exceed 4%, otherwise the voids can become interconnected and allow moisture ingress. The target compaction should be between 96% and 100% of maximum theoretical relative density (MTRD).



Paving EME

The degree of care taken with the paving operation, prior to compaction, can have a significant effect on preventing segregation. Special attention must be given to the paver settings and the way the hopper is operated – it must never be banged to loosen material stuck to the sides.

The minimum specified compacted thickness of the EME must be strictly adhered to.

A.4.3 Generally accepted rolling patterns

Raking of the layer behind the paver must be kept to an absolute minimum. Any coarse material on the surface must be carefully removed and not rolled in.

Various rolling patterns, roller weights and combinations have been successfully used. Generally, the PTR's are the first to be put onto the mat to ensure maximum compaction, with heavy steel-wheeled rollers closely behind, to iron out the surface whilst the layer is still hot. The most common rolling pattern used would be similar to the following:

- One pneumatic-tyred breakdown roller (PTR) of 18 to 22 tons must not come on before the temperature reduces to 140°C. A heavier PTR, of 27 tons, can only be used if the lift height is up to 80 mm and the paving width is greater than 4.5 metres, otherwise there will be unavoidable over-compaction, and consequent flushing, of the middle of the lane due to the additional width of the machine. The PTR increases the compaction from approximately 88% behind the paver to 93%.
- If paving up against another layer, the "pinch method" should be used, with the roller starting about 100 to 150 mm in from the edge and moving over it on the reverse pass.

The PTR is followed closely behind by:

- One twin drum vibratory roller of 6 to 8 tons. For an 80 mm or thicker lift, a 10 to 12-ton roller can be used, although it is not strictly necessary. Rolling is ineffective at temperatures <100°C.

A.4.4 Surface flushing

EME, being designed with a high binder content and low voids, can be expected to have a rich finish on completion of compaction. To limit flushing, the PTR breakdown roller should not begin rolling before the temperature behind the paver reduces to 140°C.

The density of the mat at the back of where the vibratory roller is working must be continually checked and once optimum compaction has been achieved, the roller must be kept off it, otherwise over-compaction may result.

The surfacing layer should be paved over the EME as soon as possible to prevent thermal cracking.

A.4.4 Paving over bridge decks

If EME is to be paved on a bridge deck, the designer must ensure that the bridge can accommodate the heavy compaction effort required.

A.4.5 Opening the road to traffic

Traffic should be preferably kept off the layer until the surfacing has been paved. If this is not possible, traffic **must not be allowed** onto the newly paved layer until the surface temperature is 30°C or less.

A.5 Sampling of EME

A.5.1 At the asphalt plant

Samples shall be taken at the weighbridge to ensure that they can be processed as soon as possible. The batch number and truck license number must be recorded, to be able to position the load on the road. A minimum of 6 samples should also be taken and tested for the Performance Grading (PG) requirements.

The Richness Modulus is a good indicator to judge whether there is sufficient binder in the mix. However, if the binder content is within specification but at the bottom end of its tolerance, or if the -0.075mm content increases, the Richness Modulus needs to be checked to ensure that it is still within specification.



Responsible person

It is imperative for the SANS 9001: Quality Management Plan to include a responsibility matrix, indicating the “go-to” person for each activity. This is essential, not arbitrary. Each activity must be signed off by the responsible person(s) for every paving day or night.

A.5.2 Coring

A minimum of 6 cores should be taken and tested for compaction, grading and binder content. The Richness Modulus is a good indicator to judge whether or not there is sufficient binder in the mix. However, if the binder content is within specification but at the bottom end of its tolerance, or if the -0.075mm content increases, the Richness Modulus needs to be checked to ensure that it is still within specification.

A.5.3 Further reading

TRH 21 – Hot Mixed Recycled Asphalt.

SANS 9001 – Quality Management Systems – Requirements.

Act 85 of 1993 – Occupational Health and Safety Act.

Act 39 of 2004 – National Environmental Management – Air Quality.

TMH5 – Sampling methods for roads construction materials

A.6 Quality

A.6.1 Recommended temperature ranges

The table below is a summary of the recommended temperatures and temperature ranges for the production and paving of EME, as given in this Chapter.

Position	Target temperature
Mixing	170°C ± 5°C
In front of the paver	≥ 150°C
Uncompacted mat behind the paver	≥ 140°C
Before the PTR begins rolling	≤ 140°C
Completion of all rolling	≥ 100°C
Placing a second lift on completed layer	≤ 30°C
Opening to traffic	≤ 30°C

A.6.2 Check sheets, quality management plans, method statements

Check sheets, quality management plans and method statements are all crucial for ensuring that the specifications are met in every way – they are working documents, not something to be filed away and forgotten about. They must be checked on a regular basis and updated as necessary. If the process is not conforming to any of the requirements, corrective action must be taken immediately, even to the extent of stopping all work.

A.6.3 Design mix

Because of the time it takes to receive the results of the Beam Fatigue tests, which can take up to two months, it should be carried out on the laboratory design mix and sent for testing as soon as possible. The remaining tests for approval can be carried out on the paving trial mix, using asphalt taken from the proposed optimum binder content section of the trial pavement. However, all specialised testing must pass and be approved before the trial pavement can be carried out.

Mistakes can be made by the most competent persons and it is therefore vital to check the calculations received from the designer and don't simply accept that they are correct. When checking, ensure also that the design is in terms of the specifications.

A.6.4 Routine testing

Routine testing on a day's production include:

- Gyrotory voids (workability test)
- Grading analysis
- Binder content
- MTRD
- Field compaction and voids
- Richness Modulus
- Durability: Modified Lottmann TSR (carried out every 20 000 tons)

A.6.5 Specialised testing

If there is a change in the source, or if the mix no longer conforms to the specification, the new mix shall be fully tested, including carrying out the following:

- Load resistance: Dynamic Modulus.
- Fatigue: Beam Fatigue Test
- Hamburg Test

South African Pavement Engineering Manual

Chapter 12: Construction Equipment and Method Guidelines

Check		Confirm/Reject (Y/N)									
2.	Aggregates										
	a. <i>Is there sufficient stockpile area</i> b. <i>Is the material recovered from each stockpile pile uniform</i>										
	<table border="1"> <thead> <tr> <th align="center">Stockpile (Size of aggregate)</th> <th align="center">Uniform Yes/No</th> <th align="center">Conformance to design grading</th> </tr> </thead> <tbody> <tr> <td> </td> <td> </td> <td> </td> </tr> <tr> <td> </td> <td> </td> <td> </td> </tr> </tbody> </table>	Stockpile (Size of aggregate)	Uniform Yes/No	Conformance to design grading							
Stockpile (Size of aggregate)	Uniform Yes/No	Conformance to design grading									
3.	Hot Storage for Binder										
	a. <i>Is capacity sufficient for the programmed rate of production</i> Capacity t Estimated daily demand t/day										
	b. <i>Are tanks fitted with automatic temperature recording systems</i>										
	c. <i>If a modified binder is to be used, are the blending facilities and methods appropriate to ensure a uniform product with the required properties</i>										
	d. <i>Is heating thermostatically controlled</i>										
	e. <i>Is there a warning system for variation in temperatures</i>										
	f. <i>Is binder circulated in tank and between tank and mixer</i>										
	g. <i>Are supply pipes lagged</i>										
	h. <i>Is there a level indicator</i>										
	i. <i>Are sampling points to specification</i>										
4.	Cold feed bins										
	a. <i>Are methods of controlling rate of feed operating smoothly</i>										
	b. <i>Are these controls accurate</i>										
	c. <i>Are precautions available to prevent spill over</i>										
	d. <i>Is there an adequate warning system if rate of feed alters</i>										
	e. <i>Is there an efficient interlock between cold feed and binder feed</i>										
	f. <i>Are fine aggregate feeds susceptible to arching</i>										
	g. <i>Is there a method of detecting and compensating for variations of moisture in the aggregates</i>										
	h. <i>Has contractor calibrated rates against RPM of belt pulley</i>										
5.	Mixing Plant										
	a. <i>Is rated capacity sufficient for the programmed rate of laying</i> Rate Capacity.....t/h Required Capacity.....t/h										
	b. <i>Are the proposed heating fuel and burners compatible</i>										
	c. <i>Is the method of control of the fuel/air mixture adequate</i>										
	d. <i>Are burners clean and nozzles to specification</i>										
	e. <i>Are drum rollers correctly set and in good conditions</i>										
	f. <i>Are drum flights in good conditions</i>										
	g. <i>Are binder spray bar and nozzles clean and in accordance with specification</i>										
	h. <i>Can position of spray bar be altered so as to control filler in mix and can adjustments be easily made</i>										
	i. <i>Method of determining temperatures of binder at plant: Is this adequate and are the results visible to the operator</i>										
	j. <i>Temperature controls of aggregate and final mix: Are these adequate and are the results available to the operator</i>										
k. <i>Is the plant fitted with suitable filler feed to allow accurate control of the filler content</i>											
6.	Emission Control										
	a. <i>Type:</i>										
	b. <i>Is dust collector matched to capacity of mixer</i>										
	c. <i>What method is used to return a portion of the recovered fines to the mix</i>										
	d. <i>What method is used for the disposal of unwanted fines</i>										
e. <i>Do emissions from the stack comply with Act 45 of 1965 (as amended)</i>											
7.	Buffer Storage										
	a. <i>Is this of adequate capacity</i>										
	b. <i>Is this properly lagged</i>										
c. <i>Do discharge gates operate smoothly</i>											
8.	Elevator between Mixer and Buffer Store										
	a. <i>Are buckets in good condition</i> b. <i>Are chains and cables in good conditions</i>										

South African Pavement Engineering Manual

Chapter 12: Construction Equipment and Method Guidelines

Check	Confirm/Reject (Y/N)
9. Steel Wheel Rollers <i>a. Are edges of rollers in good condition</i> <i>b. Is change of direction smooth (no backlash)</i> <i>c. Is roller properly ballasted (Record mass and position)</i> Mass..... t Position..... <i>d. Do wheel spray bars give a uniform cover on wheels</i> <i>e. Are wheel-cleaning mats in good condition</i> <i>f. Are scrapers in good condition and set</i> <i>g. Check for oil, fuel and hydraulic leaks</i> <i>h. Is roller free of leaks</i> <i>i. Do brakes work</i> <i>j. Is reversing smooth</i>	
10. Pneumatic Rollers <i>a. Are tyres in good condition</i> i. <i>Is there a variable pressure system for tyre pressure. If so, is it working and is pressure gauge working and visible to driver</i> ii. <i>Are all tyre pressures uniform. Note tyre pressures kPa</i> <i>b. Are rollers properly ballasted (Record mass and position)</i> Roller 1: Mass t Position Roller 2: Mass t Position <i>e. Are spray bars working uniformly</i> <i>f. Are cleaning pads in good condition</i> <i>g. Check for fuel, oil and hydraulic leaks</i> <i>h. Is roller free of leaks</i>	
11. Hand Tools, etc. <i>a. Straight edge: Is it clean and straight</i> <i>b. Rakes and shovels: Are they clean and in good condition</i> <i>c. Are thermometers available: No. Size</i>	
12. Haulage Vehicles <i>a. Are the basins clean</i> <i>b. Do tailgates open and close properly</i> <i>c. Are load covers fitted</i> <i>d. Are vehicles free from fuel, oil and hydraulic leaks</i> <i>e. Does tipping gear work</i> <i>f. Registration numbers of vehicles</i>	