Design procedure for high modulus asphalt (EME)

Manual 33  July 2015
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Design procedure for
High Modulus Asphalt (EME)

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Manual 4*  Specifications for rubber in binders
Manual 6*  Interim specifications for bitumen rubber
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*  These manuals have been withdrawn and their contents have been incorporated in TG1.
** This manual has been withdrawn and its software programme incorporated in TRH12: Flexible pavement rehabilitation investigation and design.
*** These manuals have been withdrawn and their contents have been consolidated with the second edition of Manual 10.
Technical guidelines

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TG2  Bitumen stabilised materials  2nd edition, 2009
TG3  Asphalt reinforcement for road condition  1st edition, 2008

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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.

Ultimately the design method presented in this document will be integrated into a South African Asphalt Design Method, scheduled for publication by Sabita in 2015. 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 the Asphalt Mix Design Manual for South Africa. 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 – construction and pavement design – are also covered, albeit briefly. In the section on construction, mention is made of 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.

This second edition reflects the adoption of the term EME for high modulus asphalt, instead of “HiMA” which has come to represent several other technologies, not necessarily associated with high modulus asphalt layers. Also, following work carried out by the CSIR and comparative testing in South Africa and France since the publication of the first edition, the compliance criteria for both the dynamic modulus and resistance to fatigue have been revised. Revised fatigue transfer functions, based on research carried out during 2014/15, are also presented in this edition.
**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, eThekwini 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.

**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.

**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.

**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;
- On new pavements as a base course layer;
- In rehabilitation, where between 80 and 120 mm is milled off and replaced 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 France.

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 layers of EME are constructed it is crucially important that good bonding between the two courses is achieved; and
- EME is sensitive to “under-design”.

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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.
Design of EME

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.

Process

The performance related 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.
Selection of Materials

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

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

**Filler**

As with conventional asphalt, filler is defined as the material passing the 0,075 mm (or 75 μm) 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

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

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Unit</th>
<th>Penetration grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10/20</td>
</tr>
<tr>
<td>Penetration at 25°C</td>
<td>EN 1426</td>
<td>0,1 mm</td>
<td>10-20</td>
</tr>
<tr>
<td>Softening point</td>
<td>ASTM D361</td>
<td>°C</td>
<td>58-78</td>
</tr>
<tr>
<td>Viscosity at 60°C, minimum</td>
<td>ASTM D4402(^1)</td>
<td>Pa.s</td>
<td>700</td>
</tr>
<tr>
<td>Viscosity at 135°C, minimum</td>
<td>ASTM D4402(^1)</td>
<td>mPa.s</td>
<td>750</td>
</tr>
<tr>
<td>Flash Point, minimum</td>
<td>ASTM D92</td>
<td>°C</td>
<td>245</td>
</tr>
<tr>
<td>After RTFOT:</td>
<td>ASTM D2872</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass change, maximum</td>
<td>ASTM D2872</td>
<td>%</td>
<td>-</td>
</tr>
<tr>
<td>Softening point (ring and ball), minimum</td>
<td>ASTM D36(^1)</td>
<td>°C</td>
<td>-</td>
</tr>
<tr>
<td>Increase in softening point, maximum</td>
<td>ASTM D36(^1)</td>
<td>°C</td>
<td>10</td>
</tr>
<tr>
<td>Retained penetration, minimum</td>
<td>EN 1426</td>
<td>% of original</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\) Using a shouldered ring  
\(^2\) Recommended apparatus is the RV viscometer, using SC4 spindles with thermostel system,  
\(^3\) Using a shouldered ring  

---
Design grading

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 definition of the maximum particle size and sieve sizes in use in Europe differ from the equivalent terms in SA practice. In SA, the nominal maximum aggregate size (NMAS) is defined as one sieve size larger than the first sieve to retain at least 15% of aggregate. In French practice the maximum stone size D is such that 100% of aggregate passes the sieve size 2D, 98-100% passes the 1,4 D size and 85-98% passes the sieve size D. For the time being the French definition of maximum aggregate size has been retained.

The grading guidelines for EME base course are shown in Table 4 for European sieve sizes and in Table 5 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 6 mm sieve.

Table 4: Target grading curves and envelopes for EME base course (European sieve sizes)

<table>
<thead>
<tr>
<th>Percent Passing</th>
<th>D = 10</th>
<th></th>
<th>D = 14</th>
<th></th>
<th>D = 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve size</td>
<td>min.</td>
<td>target</td>
<td>max.</td>
<td>min.</td>
<td>target</td>
</tr>
<tr>
<td>6,3 mm</td>
<td>45</td>
<td>55</td>
<td>65</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>4,0 mm</td>
<td>52</td>
<td>40</td>
<td>47</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>2,0 mm</td>
<td>28</td>
<td>33</td>
<td>38</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>0,063 mm</td>
<td>6,3</td>
<td>6,7</td>
<td>7,2</td>
<td>5,4</td>
<td>6,7</td>
</tr>
</tbody>
</table>

Table 5: Target grading curves and envelopes for EME base course (SA standard sieve sizes – SANS 3001)

<table>
<thead>
<tr>
<th>Percent Passing</th>
<th>NMPS = 10</th>
<th></th>
<th>NMPS = 14</th>
<th></th>
<th>NMPS = 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve size</td>
<td>min.</td>
<td>target</td>
<td>max.</td>
<td>min.</td>
<td>target</td>
</tr>
<tr>
<td>7,1 mm</td>
<td>48</td>
<td>56</td>
<td>68</td>
<td>53</td>
<td>56</td>
</tr>
<tr>
<td>5,0 mm</td>
<td>53</td>
<td>53</td>
<td>64</td>
<td>44</td>
<td>50</td>
</tr>
<tr>
<td>2,0 mm</td>
<td>28</td>
<td>33</td>
<td>38</td>
<td>25</td>
<td>33</td>
</tr>
<tr>
<td>0,075 mm</td>
<td>6,4</td>
<td>6,9</td>
<td>7,4</td>
<td>5,5</td>
<td>6,9</td>
</tr>
</tbody>
</table>
Layer thickness and maximum aggregate size

The average and minimum specified layer thicknesses of EME are provided in Table 6. Since EME is a principal structural layer, it is critical that the specified layer thickness is met during construction. It should be noted that the average layer thicknesses of EME are generally thinner than those specified for conventional asphalt bases or large-aggregate mixes for bases (LAMBs). This is due to the smaller stone size used in EME.

Another important consideration is that a well-designed and compacted EME layer 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.

Structurally, a relatively thin EME layer may yield the same performance as a thicker conventional asphalt base, because of the higher stiffness of EME. EME is also richer in binder which, compared to conventional base courses, offers good, if not better, resistance to fatigue cracking.

Table 6: EME layer thickness

<table>
<thead>
<tr>
<th>D (mm)</th>
<th>Average thickness (mm)</th>
<th>Minimum thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>60 to 80</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>70 to 130</td>
<td>60</td>
</tr>
<tr>
<td>20</td>
<td>90 to 150</td>
<td>80</td>
</tr>
</tbody>
</table>
**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 7 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:

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

*Where:*

$B_{ppc}$ = 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)

$\Sigma$ = 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

$\alpha = \frac{2.65}{r}$ - 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 7: Richness Modulus requirements**

<table>
<thead>
<tr>
<th>EME Class</th>
<th>Class 1</th>
<th>Class 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richness modulus $K$</td>
<td>$\geq 2.5$</td>
<td>$\geq 3.4$</td>
</tr>
</tbody>
</table>

**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-12697-31) 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 8.
Table 8: Workability requirements

<table>
<thead>
<tr>
<th>Test</th>
<th>No. of specimens</th>
<th>Method</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyratory compactor</td>
<td>3</td>
<td>ASTM D6926</td>
<td>≤ 10% Class 1 ≤ 6% Class 2</td>
</tr>
<tr>
<td>Air voids after 45 gyrations</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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.

**Permanent deformation**

The resistance against permanent deformation (rutting) of the EME is assessed by means of the Repeated Simple Shear Test at Constant Height (RSST-CH). Although differing from the procedure used in France, this method was selected, because it links the performance characteristics of EME to the SA Pavement Design System currently being developed. The test is performed in accordance with the AASHTO T320.

In view of the complexity of the RSST-CH test, the intention is to develop an additional set of deformation criteria for wheel tracker type tests at a later stage. Interim requirements are given in Table 9.

Table 9: Requirements for resistance to permanent deformation

<table>
<thead>
<tr>
<th>Test</th>
<th>No. of specimens</th>
<th>Method</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSST-CH, 55°C, 5 000 reps</td>
<td>3</td>
<td>AASHTO T320</td>
<td>≤ 1,1% strain ≤ 1,1% strain</td>
</tr>
</tbody>
</table>

**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.
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 10 have been adopted.

Table 10: Requirements for fatigue resistance

<table>
<thead>
<tr>
<th>Test</th>
<th>No. of specimens</th>
<th>Method</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam fatigue test at 10 Hz, 10°C, to 50% stiffness reduction</td>
<td>9</td>
<td>AASHTO T321</td>
<td>≥ 10⁶ reps @ 210 με</td>
</tr>
</tbody>
</table>

Summary of performance requirements

<table>
<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>No. of specimens</th>
<th>Method</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability</td>
<td>Gyratory compactor, air voids after 45 gyrations</td>
<td>3</td>
<td>ASTM D6925</td>
<td>≤ 10%</td>
</tr>
<tr>
<td>Durability</td>
<td>Modified Lottman, TSR</td>
<td>6</td>
<td>ASTM D4867M</td>
<td>≥ 0,80</td>
</tr>
<tr>
<td>Resistance to permanent deformation</td>
<td>RSST-CH, 55°C, 5000 reps</td>
<td>3</td>
<td>AASHTO T320</td>
<td>≤ 1,1% strain</td>
</tr>
<tr>
<td>Dynamic modulus</td>
<td>Dynamic modulus at 10Hz, 15°C</td>
<td>3</td>
<td>AASHTO TP62</td>
<td>≥ 16 GPa</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Beam fatigue test at 10Hz, 10°C, to 50% stiffness reduction</td>
<td>9</td>
<td>AASHTO T321</td>
<td>10⁶ reps @ 210 με</td>
</tr>
</tbody>
</table>
**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. It is recommended that the following aspects be given due consideration during construction:

- A tack coat should be applied to any substrate before laying EME, the target rate being 0.25 ℓ/m² of residual bitumen;
- Achieving good bonding between subsequent layers of EME;
- Ensuring that EME material meets all specifications, including grading, binder type and binder content;
- Maintaining the mixing temperature between 160 and 180°C – not exceeding 190°C – and a compaction temperature above 145°C;
- Providing a sufficiently stiff substrate to enable EME to be compacted to the required density;
- Uniform and adequate compaction of the layers;
- Consistent achievement of the specified thickness;
- Protection of the EME layer from thermal cracking due to significant day/night temperature variations, by the application of a wearing course of adequate thickness;
- Longitudinal construction joints for the various layers should not coincide with the wheel-path, and joints in different layers should be staggered and stepped;
- Thorough, uniform compaction is required to ensure that in-situ voids do not exceed 6%. For this state of compaction to be attained with confidence, a target value of 4% is recommended. (See Notes below).

**Notes**

1. Following comprehensive studies, the French recommend that compaction of EME should be undertaken with one of the following roller combinations:
   - Tandem vibrating rollers;
   - Mixed tandem rollers (pneumatic front, vibratory rear);
   - Static rollers plus pneumatic tyre rollers;
   - Tandem vibrating rollers plus pneumatic tyre rollers.

2. EME characteristically “stiffens up” quite suddenly during compaction 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;

3. EME, being designed as a binder-rich, low permeability mixture can be expected to have a rich finish on completion of compaction. During construction of trial sections in the UK, TRL reported that some ‘fattening up’ is normal and not an indication of potential problems.
**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.

**Analysis of Pavement Structures**

**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.

**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.
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.

Damage modelling

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.

\[ \log(\mu \varepsilon) = -0.1782 \log(\text{cycles}) + 3.5028 \]

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 \( \mu \varepsilon \)) to 130 (100 \( \mu \varepsilon \)).

Figure 3: Comparative fatigue performance of EME and conventional HMA
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:

\[
\frac{\varepsilon_p}{\varepsilon_r} = k_1 \times 10^{-3.4488}T^{1.5606}N^{0.479244}
\]

Where:

- \(\varepsilon_p\) = the accumulated plastic strain
- \(\varepsilon_r\) = 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.

\[
k_1 = (C_1 + C_2 \times \text{depth}) \times 0.328196^{\text{depth}}
\]

\[
C_1 = -0.1039 \times h_{ac}^2 + 2.4868 \times h_{ac} - 17.342
\]

\[
C_2 = -0.172 \times h_{ac}^2 + 1.7331 \times h_{ac} + 27.428
\]

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 eThekwini. 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
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