WARRIP

WESTERN AUSTRALIAN ROAD RESEARCH AND INNOVATION PROGRAM

High Modulus Asphalt (EME2)

2016-001

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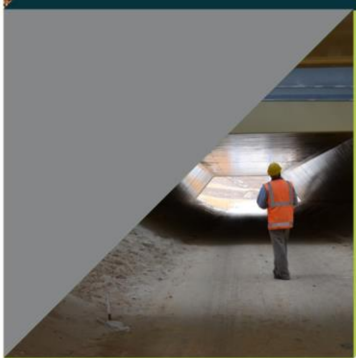
& LINCOLN LATTER



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High Modulus Asphalt (EME2)
2016-001

Report 1 of 3

for Main Roads Western Australia

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SUMMARY

The purpose of this project is to assist Main Roads Western Australia in the successful transfer of French Enrobés à Module Elevé Class 2 (EME2) technology to Australia. EME2 technology offers the prospect of reduced asphalt thicknesses for heavy duty pavements, and lower construction and maintenance costs.

EME2 mixes are produced using a hard, paving grade bitumen applied at a high binder content (approx. 6%). Compared to conventional asphalt bases with unmodified binders, EME2 asphalt is characterised by high stiffness, high durability, superior resistance to permanent deformation and improved fatigue resistance. International and Australian experience indicates that significant pavement thickness reductions can be achieved using EME2.

As part of this project, an Australia specification framework for EME2 mixes was developed and the requirements for manufacturing, paving and compliance were also provided. Initially tentative specification limits for EME2 mixes were set using Australian test methods for workability, wheel tracking, flexural stiffness, fatigue, and moisture sensitivity. A demonstration trial was also carried out as part of the validation process.

This report summarises the outcomes of the *High Modulus Asphalt (EME2)* project, which includes:

- how EME2 fits into the current Main Roads pavement design supplement relative to typical design moduli and pavement design temperatures in WA
- pavement design calculations (case studies) to assess the potential in pavement thickness reduction
- an interim EME2 mix design specification in line with the national specification framework
- European practices in design, use, construction and maintenance and determine possible barriers to implementation in WA
- documentation of a trial to ensure the design mix can be manufactured, paved and compacted to the expected standards using locally available equipment
- proposed changes to the current Main Roads EME2 specification and Engineering Road Note, as well as inclusions into the Main Roads pavement design supplement ERN9.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

1.1 Background

An effort is underway to transfer the French high modulus asphalt Enrobé à Module Élevé (EME) asphalt technology to Western Australia. The distinctive component of EME asphalt mixes is a hard paving grade bitumen applied at a relatively high binder content (approximately 6%). EME2 (EME Class 2) is used as an asphalt base layer. Compared to conventional asphalt bases with unmodified binders, high modulus asphalt is characterised by a high stiffness, high durability, superior resistance to permanent deformation and satisfactory fatigue resistance.

International experience indicates that significant pavement thickness reductions can be achieved without compromising the pavement performance. The implementation of EME2 may be beneficial to Western Australia where traffic loads have grown substantially, particularly in mining areas such as the Pilbara region. Heavy duty applications require asphalt pavements of substantial thickness. As conventional full depth asphalt (FDA) pavement may not be a cost-effective solution due to the substantial thickness required, Main Roads plans to investigate the use of EME2 as an alternative to concrete pavements.

1.2 Objectives and Approach

The main outcomes for the *High Modulus Asphalt (EME2)* project include the modification and development of technical guidance regarding specifications for EME2 mix design, compaction and placement of asphalt layers in line with the national specification framework.

The objective project was undertaken by adopting the following approach:

- determining how EME2 fits into the current Main Roads pavement design supplement relative to typical design moduli and pavement design temperatures in WA – Section 2
- conducting pavement design calculations (case studies) to assess the potential in pavement thickness reduction – Section 2
- developing an interim EME2 mix design specification in line with the national specification framework – Section 3
- identifying European practices in design, use, construction and maintenance and determine possible barriers to implementation in WA such as materials, plant, paving experience, guidance on use – Section 4
- observing the EME2 production and construction processes as conducted by the Queensland Department of Transport and Main Roads to implement best practice for the Main Roads trial – Section 5
- conducting a trial to ensure the design mix can be manufactured, paved and compacted to the expected standards using locally available equipment – Section 6
- summarising the current national EME2 implementation – Section 7
- finalising the EME2 specification and the section on the inclusion of EME2 in the Main Roads pavement design supplement – Section 8.

2 EME2 PAVEMENT DESIGN CALCULATIONS FOR WESTERN AUSTRALIAN CONDITIONS

The purpose of this section is to compare the overall asphalt thicknesses using Engineering Road Note 9 (ERN9) design guides of Main Roads Western Australia (Main Roads) for different type of asphalt material as follows:

1. using AC14 and/or AC20 dense graded intermediate asphalt course used as structural asphalt layer
2. replacing the intermediate asphalt course with EME2.

Initially four full depth asphalt (FDA) heavy duty pavement structures were identified by Main Roads and these were modelled using the existing pavement configurations (as control) and alternatively with EME2. The following pavement sections were selected for this analysis using CIRCLY5.0:

1. Kwinana Freeway Northbound / Russell Road intersection
2. Kwinana Freeway Southbound / Gibbs Road intersection
3. Gibbs Road / Lyon Road intersection
4. Kwinana Freeway Northbound off ramp H692 widening.

2.1 Intermediate Asphalt Course (IAC) using AC14 and/or AC20

Table 2.1 summarises the material properties used in different pavement layers for the selected pavement sections. The weighted mean annual pavement temperature (WMAPT) is 29 °C for Perth and this value was used in the calculations throughout.

Table 2.1: Main Roads FDA design material properties

Design ID	Location	Design speed (km/h)	Material type of each layer	Design modulus (MPa)	In situ air voids (%)	In situ binder volume (%)
FDA1	Kwinana Freeway NB / Russell Road Intersection	10	14 mm intersection mix (A15E)	1000	8.8	10.3
			14 mm IAC (A15E)	1000	8.8	10.3
			20 mm IAC (A15E)	1290	5.4	10.3
			20 mm IAC (Class 320)	1710	5.4	10.3
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A
FDA2	Kwinana Freeway SB / Gibbs Road Intersection	10	14 mm intersection mix (A15E)	1000	8.8	11.8
			14 mm IAC (A15E)	1000	8.8	10.3
			20 mm IAC (A15E)	1290	5.4	10.3
			20 mm IAC (Class 320)	1710	5.4	10.3
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A
FDA3	Gibbs Road / Lyon Road Intersection	10	14 mm intersection mix (A15E)	1000	8.8	10.3
			14 mm IAC (A15E)	1000	8.8	10.3
			20 mm IAC (A15E)	1290	5.4	10.3

Design ID	Location	Design speed (km/h)	Material type of each layer	Design modulus (MPa)	In situ air voids (%)	In situ binder volume (%)
			20 mm IAC (Class 320)	1710	5.4	10.3
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A
FDA4	Kwinana Freeway NB off ramp H692 Widening	60	10 mm OGA	800	N/A	N/A
			14 mm intersection mix (A15E)	1760	8.8	10.3
			14 mm IAC (A15E)	1760	8.8	10.3
			20 mm IAC (A15E)	2470	5.4	10.3
			20 mm IAC (Class 320)	3300	5.4	10.3
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A

Source: Main Roads.

The k values used for the fatigue equation is one of the most important CIRCLY inputs for different asphalt materials and it is determined using Equation 1 (Austroads 2012).

$$k = \frac{6918(0.856V_b + 1.08)}{S_{mix}^{0.36}} \qquad 1$$

where

V_b = percentage by volume of bitumen in the asphalt (%)

S_{mix} = asphalt modulus (MPa).

According to ERN9, when the mechanistic procedure is used for flexible pavement design the design traffic in terms of equivalent standard axles (ESAs) should be converted to standard axle repetitions (SARs) for each damage category. For this reason, related traffic multipliers (shown in Table 2.2) were used in the CIRCLY for pavement analysis and design.

Table 2.2: Presumptive SARs for general use in pavement design

Main Roads WA road classification	Asphalt fatigue	Rutting and shape loss	Cemented material fatigue
	SAR5/ESA	SAR7/ESA	SAR12/ESA
Rural national highways	1.26	2.31	21.40
Rural highways	1.22	1.93	9.42
Rural main and secondary roads	1.13	1.53	4.66
Urban freeways and highways	1.13	1.64	9.78
Other important urban arterial roads	1.13	1.64	9.78

Source: Main Roads (2013).

In this study a traffic multiplier of 1.13 was used for all asphalt layers and a traffic multiplier of 1.64 was used for the subgrade layer. Table 2.3 shows a summary of CIRCLY5.0 inputs and outputs for the control pavement design.

Table 2.3: Main Roads FDA design

Design ID	CIRCLY5.0 input				CIRCLY5.0 output	
	Design traffic (ESA)	Material type of each layer	Parameter k	Nominal thickness (mm)	Modelled thickness (mm)	Cumulative damage factor (CDF)
FDA1	3.00E+7	14 mm intersection mix (A15E)	5695	40	40	
		14 mm IAC (A15E)	5695	50	50	
		20 mm IAC (A15E)	5196	60	60	
		20 mm IAC (Class 320)	4695	155	145	8.93E-01
		Crushed limestone	NA	200	200	
		Sand subgrade CBR 12%	NA	Infinite	Infinite	4.8E-04
FDA2	9.00E+7	14 mm intersection mix (A15E)	6434	40	40	
		14 mm IAC (A15E)	5695	50	50	
		20 mm IAC (A15E)	5196	60	60	
		20 mm IAC (Class 320)	4695	200	190	9.48E-01
		Crushed limestone	NA	200	200	
		Sand subgrade CBR 12%	NA	Infinite	Infinite	3.8E-04
FDA3	2.00E+7	14 mm intersection mix (A15E)	5695	40	40	
		14 mm IAC (A15E)	5695	50	50	
		20 mm IAC (A15E)	5196	60	60	
		20 mm IAC (Class 320)	4695	135	125	9.74E-01
		Crushed limestone	NA	200	200	
		Sand subgrade CBR 12%	NA	Infinite	Infinite	6.1E-04
FDA4	8.00E+7	10 mm OGA	NA	30	30	
		14 mm intersection mix (A15E)	4646	40	40	
		14 mm IAC (A15E)	4646	50	50	
		20 mm IAC (A15E)	4112	60	60	
		20 mm IAC (Class 320)	3705	50	40	1.00E-01
		Crushed limestone	NA	200	200	
		Sand subgrade CBR 12%	NA	Infinite	Infinite	5.38E-04

Source: Main Roads.

2.2 EME2 Pavement Design Calculations

2.2.1 EME2 Pavement Design Parameters

Table 2.4 provides a summary of material property used in different pavement layers for selected FDA pavements. The values in Table 2.4 for EME2 were derived from Technical Note (TN) 142 (TMR 2015) following temperature correction to 29 °C, which is the WMAPT in Perth. The presumptive binder volume of 13.5% was adopted from TN142.

Guide to Pavement Design Part 2: Pavement Structural Design (Austroads 2012) provides a temperature and speed correction relationship for modulus for determination of design modulus of asphalt from laboratory indirect tensile strength modulus testing using conventional binders (Equation 2 and Equation 3).

$$\frac{\text{Modulus at WMAPT}}{\text{Modulus at test temperature (T)}} = e^{-0.08(\text{WMAPT}-\text{T})} \quad (2)$$

$$\frac{\text{Modulus at speed V}}{\text{Modulus at test loading rate}} = 0.19V^{0.365} \quad (3)$$

Table 2.4: EME2 design modulus for different design speeds and temperatures

Design speed (km/h)	Brisbane metro area		Perth metro area			
	WMAPT (°C)	Modulus at 32 °C (MPa)	WMAPT (°C)	Modulus at 29 °C (MPa)	Rounded design modulus (MPa)	Parameter k
90	32	N/A	29	5561	5600	3921
80	32	4200	29	5339	5300	3989
60	32	3780	29	4807	4800	4134
50	32	3600	29	4576	4500	4231
30	32	3000	29	3814	3800	4496
10	32	2000	29	2542	2500	5228

Cores were extracted from the EME2 trial on the Cullen Avenue West, Eagle Farm in Queensland and the resilient modulus of the cores was determined according to AS/NZS 2891.13.1 at the standard test temperature of 25 °C, as well as at 15, 32 and 40 °C.

It was found that the AGPT relationship was valid for EME2 across a range of temperatures normally considered for Australian climatic conditions. It should be noted that EME2 is manufactured using conventional bitumen, i.e. plain binder, not modified binder. EME2 performed as expected, i.e. the correction factors were found to be valid. Similar test regime was conducted for the Victorian trial, which was constructed in June 2015 on the South Gippsland Highway, between Monomeith and Caldermeade, Victoria and it was found that the correction factors are valid for the Victorian mix.

To validate the correction factors for WA conditions, bulk production samples were collected from the EME2 trial in WA and laboratory test specimens were prepared; the specimens will be subjected to similar test regime as per above. Cores extracted from the completed pavement were tested to determine the properties of the EME2 trial pavement.

2.2.2 Intermediate Asphalt Course as EME2 – Pavement Design Calculations

Table 2.5 summarises the material properties used for EME2 pavement design calculations. The asphalt thicknesses indicated in the below calculations are modelled thicknesses and require the addition of 10 mm for construction tolerances.

Table 2.5: EME2 design material properties

Design ID	Location	Design speed (km/h)	Material type of each layer	Design modulus (MPa)	In situ air void (%)	In situ binder volume (%)
		10	14 mm intersection mix (A15E)	1000	8.8	10.3

Design ID	Location	Design speed (km/h)	Material type of each layer	Design modulus (MPa)	In situ air void (%)	In situ binder volume (%)
FDA1-EME2	Kwinana Freeway NB / Russell Road Intersection		EME2	2500	<5.5	13.5
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A
FDA2-EME2	Kwinana Freeway SB / Gibbs Road Intersection	10	14 mm intersection mix (A15E)	1000	8.8	11.8
			EME2	2500	<5.5	13.5
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A
FDA3-EME2	Gibbs Road / Lyon Road Intersection	10	14 mm intersection mix (A15E)	1000	8.8	10.3
			EME2	2500	<5.5	13.5
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A
FDA4-EME2	Kwinana Freeway NB off ramp H692 Widening	60	10 mm OGA	800	N/A	N/A
			14 mm intersection mix (A15E)	1760	8.8	10.3
			EME2	4800	<5.5	13.5
			Crushed limestone	150	N/A	N/A
			Sand subgrade CBR 12%	120	N/A	N/A

Table 2.6 summarises the pavement design details for the FDA pavements where only the lowest asphalt layer was substituted by EME2 and Table 2.7 shows the details for EME2 pavements where all intermediate asphalt layers were substituted by EME2.

Table 2.6: EME2(A) pavement designs – only the lowest asphalt layer substituted for EME2

ID No	CIRCLY5.0 input			CIRCLY5.0 output	
	Design traffic (ESA)	Material type	Parameter k	Modelled thickness (mm)	Cumulative damage factor (CDF)
FDA 1 – EME2(A)	3.00E+7	14 mm intersection mix (A15E)	5695	40	N/A
		14 mm IAC (A15E)	5695	50	N/A
		20 mm IAC (A15E)	5196	60	N/A
		EME2	5228	90	8.98E-01
		Crushed limestone	N/A	200	N/A
		Sand subgrade CBR 12%	N/A	N/A	2.02E-03
FDA 2– EME2(A)	9.00E+7	14 mm intersection mix (A15E)	6434	40	N/A
		14 mm IAC (A15E)	5695	50	N/A
		20 mm IAC (A15E)	5196	60	N/A
		EME2	5228	130	9.15E-01
		Crushed limestone	N/A	200	N/A

ID No	CIRCLY5.0 input			CIRCLY5.0 output	
	Design traffic (ESA)	Material type	Parameter k	Modelled thickness (mm)	Cumulative damage factor (CDF)
		Sand subgrade CBR 12%	N/A	N/A	1.38E-03
FDA 3–EME2(A)	2.00E+7	14 mm intersection mix (A15E)	5695	40	N/A
		14 mm IAC (A15E)	5695	50	N/A
		20 mm IAC (A15E)	5196	60	N/A
		EME2	5228	75	9.15E-01
		Crushed limestone	N/A	200	N/A
		Sand subgrade CBR 12%	N/A	N/A	2.44E-03
FDA 4–EME2(A)	8.00E+6	10 mm OGA	N/A	30	N/A
		14 mm intersection mix (A15E)	4646	40	N/A
		14 mm IAC (A15E)	4646	50	N/A
		20 mm IAC (A15E)	4112	60	N/A
		EME2	4134	15 (1)	8.58E-01
		Crushed limestone	N/A	200	N/A
		Sand subgrade CBR 12%	N/A	N/A	1.43E-03

1 EME2 layer is too thin for this calculation, pavement composition is not constructible.

Table 2.7: EME2(B) pavement designs – all intermediate asphalt layers substituted by EME2

Design ID	CIRCLY5.0 input			CIRCLY5.0 output	
	Design traffic (ESA)	Material type	Parameter k	Modelled thickness (mm)	Cumulative damage factor (CDF)
FDA1-EME2(B)	3.00E+7	14 mm intersection mix (A15E)	5695	40	N/A
		EME2	5228	180	9.6E-0.1
		Crushed limestone	NA	200	N/A
		Sand subgrade CBR 12%	NA	Infinite	1.81E-03
FDA2-EME2(B)	9.00E+7	14 mm intersection mix (A15E)	6434	40	N/A
		EME2	5228	220	9.50E-01
		Crushed limestone	NA	200	N/A
		Sand subgrade CBR 12%	NA	Infinite	1.16E-03
FDA3-EME2(B)	2.00E+7	14 mm intersection mix (A15E)	5695	40	N/A
		EME2	5228	165	9.97E-01
		Crushed limestone	NA	200	N/A
		Sand subgrade CBR 12%	NA	Infinite	2.27E-03
FDA4-EME2(B)	8.00E+6	10 mm OGA	NA	30	N/A
		14 mm intersection mix (A15E)	4646	40	N/A
		EME2	4134	100	8.65E-01
		Crushed limestone	NA	200	N/A
		Sand subgrade CBR 12%	NA	Infinite	2.17E-03

2.2.3 Overall Asphalt Thickness Reduction using EME2 as Intermediate Course

Table 2.8 shows the overall thickness reductions after replacing the asphalt intermediate layers with EME2.

Table 2.8: Overall asphalt thickness reduction using EME2 as intermediate course

ID No.	Location	Design ID	Which layer substituted by EME2	Total asphalt thickness (mm)	Asphalt thickness reduction using EME2 (mm)
1	Kwinana Freeway NB / Russell Road Intersection	FDA1	Original design	305	N/A
		FDA1-EME2(A)	Only the lowest asphalt layer substituted	240	65
		FDA1-EME2(B)	All intermediate asphalt layer substituted	220	85
2	Kwinana Freeway SB / Gibbs Road Intersection	FDA2	Original design	350	N/A
		FDA2-EME2(A)	Only the lowest asphalt layer substituted	280	70
		FDA2-EME2(B)	All intermediate asphalt layer substituted	260	90
3	Gibbs Road / Lyon Road Intersection	FDA3	Original design	285	N/A
		FDA3-EME2(A)	Only the lowest asphalt layer substituted	225	60
		FDA3-EME2(B)	All intermediate asphalt layer substituted	205	80
4	Kwinana Freeway NB off ramp H692 Widening	FDA4	Original design	240	N/A
		FDA4-EME2(A) (1)	Only the lowest asphalt layer substituted	195	45
		FDA4-EME2(B)	All intermediate asphalt layer substituted	170	70

1 EME2 layer is too thin for this calculation, pavement composition is not constructible.

2.3 Further EME2 Pavement Compositions

2.3.1 On and Off-ramp Pavements with Binder (Intermediate) Course

The previously modelled FDA pavements in Table 2.3 were re-calculated using a third pavement configuration. In these pavement structures, a binder (intermediate) course was used directly underneath the wearing course and the asphalt layers underneath were replaced by EME2.

The rationale behind this was that in France for heavy traffic above TC5 (which is medium volume traffic loading), a binder course (intermediate layer) between the EME2 and the wearing course layer is specified. The additional binder course under heavy traffic serves two purposes:

- the longitudinal profile and evenness requirements are strict in France and an intermediate asphalt layer between the base (EME2) and the wearing course provides control to comply with the riding quality requirements
- when the pavement is due for scheduled maintenance (replacement of the wearing course), the EME2 layer remains intact in this process.

For the re-calculations of the FDAs in Table 2.3, where the wearing course was a 14 mm intersection mix, a 14 mm intermediate course at 50 mm thickness was included as a binder course; the results are summarised in Table 2.9. The asphalt thickness reduction is shown in Table 2.10 which is the updated version of the initial calculations in Table 2.8 and indicates the minimum number of paving runs according to the following:

- nominal 20 mm asphalt intermediate course shall be placed in layers of compacted thickness not less than 60 mm and not greater than 90 mm (Specification 510)

- nominal 14 mm asphalt intermediate course shall be placed in layers of compacted thickness not less than 45 mm or greater than 55 mm (Specification 510 (Main Roads 2017))
- EME2 asphalt shall be placed in layers of compacted thickness not less than 70 mm and not greater than 130 mm.

Table 2.9: EME2 pavement designs – wearing course and binder layer combined with EME2

Design ID	Design traffic (ESA)	Material type	Parameter k	Modelled thickness (mm)	Cumulative damage factor (CDF)
FDA1-EME2(C)	3.00E+07	14 mm intersection mix (A15E)	5695	40	N/A
		14 mm IAC (A15E)	5695	50	N/A
		EME2	5228	140	9.66E-01
		Crushed limestone	N/A	200	N/A
		Sand subgrade CBR 12%	N/A	N/A	2.12E-03
FDA2-EME2(C)	9.00E+07	14 mm intersection mix (A15E)	6434	40	N/A
		14 mm IAC (A15E)	5695	50	N/A
		EME2	5228	180	9.61E-01
		Crushed limestone	N/A	200	N/A
		Sand subgrade CBR 12%	N/A	N/A	1.38E-03
FDA3-EME2(C)	2.00E+07	14 mm intersection mix (A15E)	5695	40	N/A
		14 mm IAC (A15E)	5695	50	N/A
		EME2	5228	125	9.95E-01
		Crushed limestone	N/A	200	N/A
		Sand subgrade CBR 12%	N/A	N/A	2.62E-03
FDA4-EME2(C)	8.00E+06	10 mm OGA	N/A	30	N/A
		14 mm intersection mix (A15E)	4646	40	N/A
		EME2	4134	100	8.65E-01
		Crushed limestone	N/A	200	N/A
		Sand subgrade CBR 12%	N/A	N/A	2.17E-03

Table 2.10: Overall asphalt thickness reduction using EME2 in different asphalt layer combinations

ID No.	Location	Design ID	Which layer substituted by EME2	Total asphalt thickness (mm)	Asphalt thickness reduction using EME2 (mm)	Minimum number of paving runs
1	Kwinana Freeway NB / Russell Road Intersection	FDA1	Original design	305	N/A	5
		FDA1-EME2(A)	Only the lowest asphalt layer substituted	240	65	4
		FDA1-EME2(B)	All intermediate asphalt layer substituted	220	85	3
		FDA1-EME2(C)	Wearing course and binder course combined with EME2	230	75	4
2		FDA2	Original design	350	N/A	6

ID No.	Location	Design ID	Which layer substituted by EME2	Total asphalt thickness (mm)	Asphalt thickness reduction using EME2 (mm)	Minimum number of paving runs
	Kwinana Freeway SB / Gibbs Road Intersection	FDA2-EME2(A)	Only the lowest asphalt layer substituted	280	70	4
		FDA2-EME2(B)	All intermediate asphalt layer substituted	260	90	3
		FDA2-EME2(C)	Wearing course and binder course combined with EME2	270	80	4
3	Gibbs Road / Lyon Road Intersection	FDA3	Original design	285	N/A	5
		FDA3-EME2(A)	Only the lowest asphalt layer substituted	225	60	4
		FDA3-EME2(B)	All intermediate asphalt layer substituted	205	80	3
		FDA3-EME2(C)	Wearing course and binder course combined with EME2	215	70	3
4	Kwinana Freeway NB off ramp H692 Widening	FDA4	Original design	240	N/A	5
		FDA4-EME2(A)(1)	Only the lowest asphalt layer substituted	195	N/A	N/A
		FDA4-EME2(B)	All intermediate asphalt layer substituted	170	70	3
		FDA4-EME2(C)	Wearing course and binder course combined with EME2	170	70	3

1 EME2 layer is too thin for this calculation, pavement composition is not constructible.

2.3.2 Mid-block Pavement Calculations

The initial calculations were completed for on and off-ramp pavements. There was a need identified to conduct EME2 pavement designs for main carriageway pavement structures. An option was investigated modelling mid-block (i.e. main carriageway) pavement composition for a heavily trafficked road section. Main Roads nominated the widening of the Kwinana Freeway, southbound carriageway between Armadale Road to Russell Road for these calculations.

For the mid-block pavement calculation, to maintain consistency with the original pavement composition, a 30 mm thick 10 mm OGA (Class 320) and 30 mm thick 10 mm DGA (A15E) was adopted. The latter layer was considered as the binder course according to the French context (Section 2.3.1). Table 2.11 summarises the results; the EME2 pavement is 75 mm thinner compared to the original FDA design. Also, the number of paving runs decreases to four from five compared to the control FDA pavement.

Table 2.11: Kwinana freeway main carriageway widening between Armadale Rd and Russel Rd, FDA pavement designs

Design ID	Design traffic (ESA)	Material type	Parameter k	Modelled thickness (mm)	Design modulus (MPa)	Cumulative damage factor (CDF)
Original FDA pavement design 90 km/h	2.20E+08	10 mm OGA (Class 320)		30	800	
		10 mm DGA (A15E)	5007	30	1430	
		14 mm IAC (A15E)	4406	50	2040	
		20 mm IAC (A15E)	3896	60	2870	
		20 mm IAC (Class 320)	3515	165	3820	9.62E-01
		Crushed limestone		200		
		Sand subgrade CBR 12%			120	1.46E-04
	Total asphalt layer thickness (mm)			**335**		
EME2 FDA pavement design 90 km/h	2.20E+08	10 mm OGA (Class 320)		30	800	
		10 mm DGA (A15E)	5007	30	1430	
		EME2	3921	200	5560	9.10E-01
		Crushed limestone		200		
		Sand subgrade CBR 12%			120	4.63E-04
	Total asphalt layer thickness (mm)			**260**		

2.3.3 Trial Section Tonkin Highway – Kelvin Road Intersection

Main Roads nominated the Tonkin Highway, Kelvin Road intersection for a potential EME2 trial, to be carried out towards the end of 2016. Main Roads provided the traffic calculations, which is summarised in Table 2.12.

Table 2.12: Tonkin Highway – Kelvin Road intersection, design traffic data

Road/carriageway	Design traffic (ESA)	SAR5/ESA	SAR7/ESA	SAR12/ESA
Tonkin Hwy, Northbound carriageway	6.6E+07	1.13	1.64	9.78
Tonkin Hwy, Southbound carriageway	6.0E+07			
Kelvin Road through carriageway	1.0E+07			
Kelvin Road turning lane	3.8E+07			

Source: Main Roads.

In April 2016 an EME2 trial was planned for construction on the third lane of the Tonkin Highway, adjacent to the left slip lane, with the trial potentially running through the intersection itself. However, it was not decided which carriageway would be selected for the trial, therefore the EME2 pavement designs were carried out for both carriageways; the results are summarised in Table 2.13. For practical reasons the pavement composition of the trial excludes the binder (intermediate) course.

The EME2 trial pavement could be constructed in two EME2 paving runs and one paving run of the wearing course.

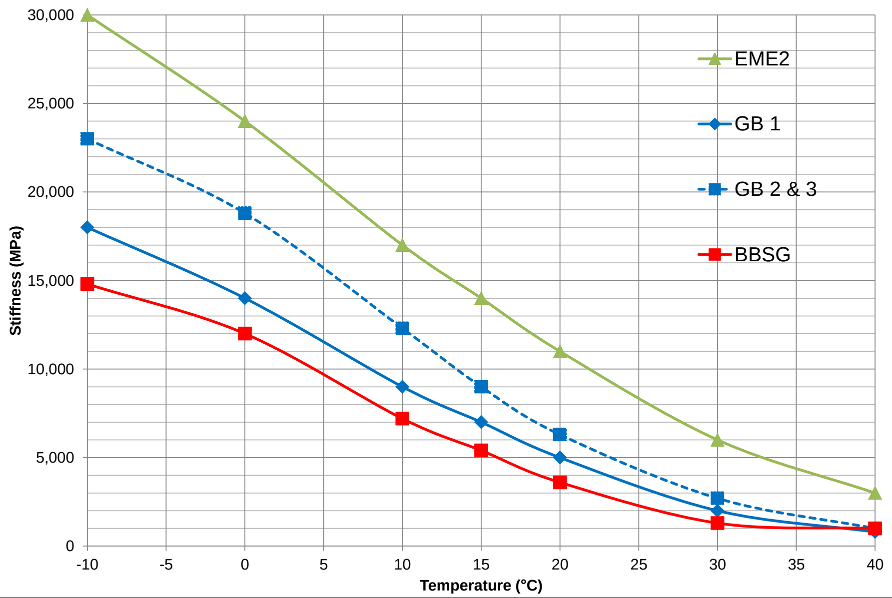
Table 2.13: Tonkin Highway – Kelvin Road intersection, pavement design details (10 km/h)

Design ID	Material type	Modelled thickness (mm)	Parameter k	Cumulative damage factor (CDF)
Tonkin NB through carriageway	14 mm intersection mix (A15E)	40	5695	
	EME2	220	5228	8.91E-01
	Crushed limestone	150		
	Sand subgrade CBR 10%			3.6E-03
	Asphalt thickness (mm)	**260**		
Tonkin SB through carriageway	14 mm intersection mix (A15E)	40	5695	
	EME2	215	5228	9.25E-01
	Crushed limestone	150		
	Sand subgrade CBR 10%			3.9E-03
	Asphalt thickness (mm)	**255**		

2.3.4 *Pavement Design According to the French Pavement Design Method*

The Tonkin Highway trial the pavement structure was checked using the general mechanistic procedure according to NF P 98-086 (2011), outlined in *Cost-effective Design of Thick Asphalt Pavements: High Modulus Asphalt Implementation* (Petho 2014). The pavement response was calculated using the software package ALIZÉ. The WMAPT for Perth is 29 °C, and the stiffness values were selected accordingly. The design modulus value for EME2 mix was adopted from Laboratoire Central des Ponts et Chaussées (LCPC) (1997), which is in line with the material library of the software package ALIZÉ (Figure 2.1).

Figure 2.1: Temperature dependency of different asphalt types (complex modulus at 10 Hz, 2-point bending)



Source: Laboratoire Central des Ponts et Chausées (1997).

The design input parameters and assumptions for the asphalt mixes are shown in Table 2.14. For the calculation of the allowable strains, when using the French pavement design method, the following should be considered and noted:

- For the French design, the fatigue properties were calculated according to NF P 98-086 (2011). The methodology of calculation is explained in detail in Section 3.1.

- For the pavement design calculations, the minimum mix performance requirements were considered, i.e. 14 000 MPa stiffness at 15 °C, 10 Hz and 130 microstrain at 10 °C, 25 Hz.

Table 2.14: Design input parameters for the Australian design procedure

Asphalt type	Design stiffness (MPa)
BBSG (similar to 14 mm intersection mix)	1250 (1)
EME2	6400 (1)
Crushed limestone	150
Sand subgrade CBR 10%	100

1 Refer to Figure 2.1.

It should be noted that the Australian and French pavement design methods cannot be directly compared; although they both utilise the mechanistic procedure, the amplitude of traffic loadings, shift factors, reliability factors and fatigue properties are calculated and determined in different ways. The major differences between the design procedures are summarised in Table 2.15.

Table 2.15: Comparison of the French and Australian pavement design input

Input	French method	Australian method
Number of vehicles	Similar	
Design traffic (NDT)	N/A	Required
Traffic load in equivalent standard axles $(NE)_{pavement}$	Required	N/A
Equivalent standard axles (ESA)	N/A	Required
Material parameters	Different	
Fatigue equations	Different	
Pavement design outcome	Similar	

The outcomes of the French pavement design for the Tonkin Highway trial are summarised in Table 2.16. According to the calculations the pavement consists of 230 mm EME2 covered by 40 mm wearing course. The thickness of the EME2 layer (230 mm) is identical with the thickness of the EME2 layer when designed using the Australian methodology (220 mm + 10 mm tolerance = 230 mm).

Table 2.16: Tonkin Highway, EME2 trial, pavement design according to the French method (NF P 98-086 / ALIZE)

Material type	Modulus (MPa)	Model 1		Model 2		Model 3		Allowable strain (microstrain)
		Thickness (mm)	Calculated strain (microstrain)	Thickness (mm)	Calculated strain (microstrain)	Thickness (mm)	Calculated strain (microstrain)	
BBSG	1250	40	N/A	40	N/A	40	N/A	N/A
EME2	6400	210	72.6 (1)	220	68.3 (1)	230	64.3 (2)	**67.4**
Crushed rock	150	150	N/A	150	N/A	150	N/A	N/A
Sand subgrade	100	N/A	194.4	N/A	182.2	N/A	171.2	**255.0**

1 Calculated strain is greater than allowable strain.
2 Calculated strain is lower than allowable strain.

The calculation of the allowable strain according to the French pavement design method is summarised in Table 2.17; the details are provided in Section 3.1.

Table 2.17: Pavement thickness design according to the French method (NF P 98-086 / ALIZE), EME2

Pavement structure	Property	EME2 allowable strain calculation input
Formation support	MPa	100
Traffic	Annual average daily traffic (AADT) (traffic class TS-)	1690
	Design period - p (year)	40
	Annual growth rate (τ) (%)	2.6
	Cumulative growth factor over design period (C)	69
	Mean traffic aggressiveness (CAM) ($_{pavement}$)	0.8
	NE ($_{pavement}$)	33 933 920
	Number of heavy vehicles over design period (NPL)	42 417 400
Allowable subgrade vertical strain	Medium-heavy traffic	0.012
	CAM (subgrade)	0.8
	NE	33 933 920
	Exponent	–0.222
	$\varepsilon_{vertical}$	**255 E-06**
Allowable asphalt horizontal strain	T $_{equivalent}$	29
	E (10 °C, 10 Hz) (MPa)	17 000
	E (32 °C, 10 Hz) (MPa)	6 400
	ε_6 (10 °C, 25 Hz)	130E-6
	ε_6 (29 °C, 10 Hz)	105E-6
	Pavement thickness (cm)	26
	Formation support (MPa)	100
	Risk level associated with traffic class (%)	1
	Variable associated with risk (u)	–2.326
	Slope of the fatigue line (b)	-0.2
	Coefficient c	0.02
	Standard deviation of pavement thickness (Ss_h)	2.5
	Standard deviation of the fatigue test (S_N)	0.25
	Standard deviation at distribution of logN at failure (δ)	0.354
	Coefficient kr	0.685
	Coefficient kc	1.0
	Coefficient ks	0.94
	$\varepsilon_{t, allow}$	**67.4 E-06**

2.3.5 Objectives of the Trial

The objectives of the EME2 trial in WA are summarised as follows:

- General objectives:
  - select a suitable test site for the first EME2 trial in WA
  - develop draft EME2 guideline for designing pavements containing EME2, using the Austroads pavement design methodology (Austroads 2012) and ERN9

- design and construct a full depth EME2 asphalt pavement covered with a standard wearing course
- manufacture EME2 mix in line with *Draft Specification 514 High Modulus Asphalt (EME2)*; the design mix, used for the trial, should be validated overseas according to the EN specifications
- develop a test plan for monitoring production and paving of the trial; this will also provide the basis for the long-term monitoring of the trial site
- report the findings of the trial, specifically the manufacture, paving conditions, testing of the binder and asphalt properties; use this information as a feedback for finalising Specification 514 and ERN9.

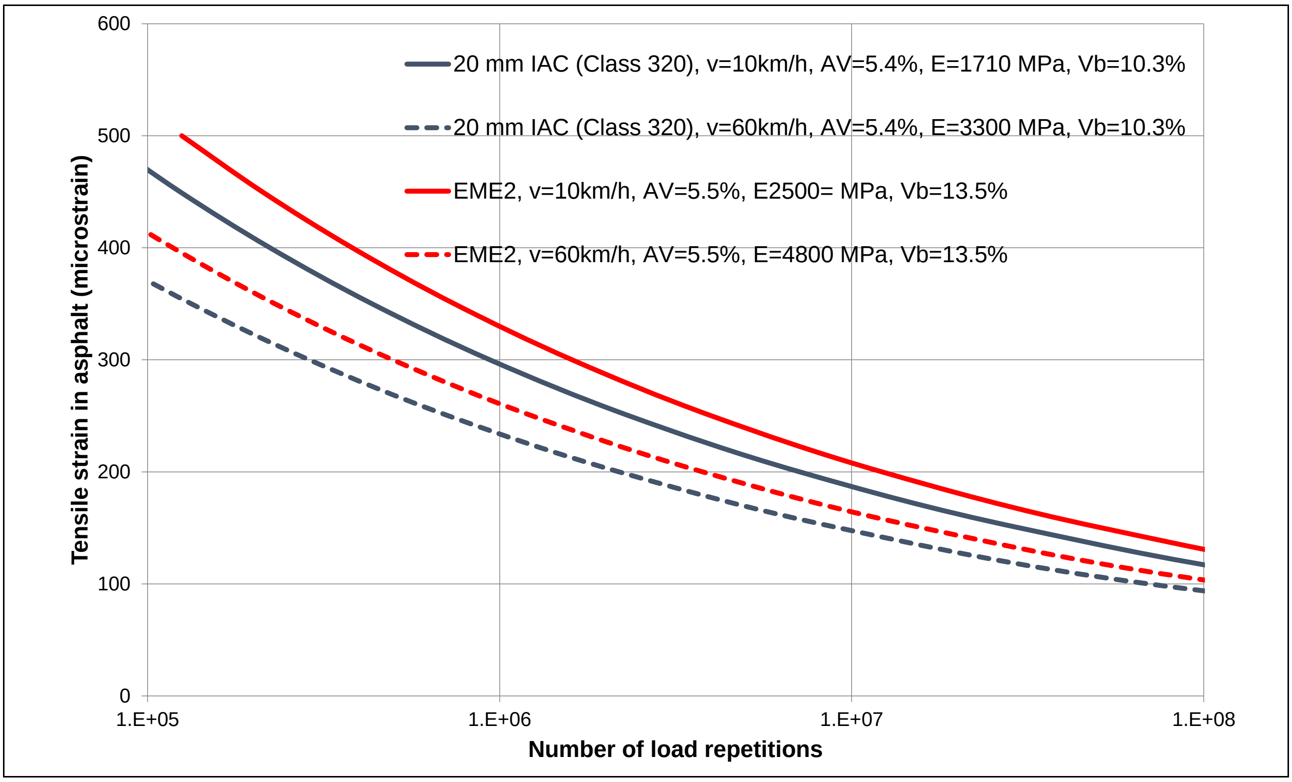
- Assess the feasibility of production and construction of EME2 using asphalt plants and road construction equipment available in WA:
  - use asphalt production control data to assess the variability of EME2 during production
  - analyse in situ air voids content and check the level of compaction; for EME2 low in situ air voids are required
  - measure material response and compaction curve to establish proper rolling pattern; record the temperatures throughout production and paving
  - increase experience with surface characteristics and assess the potential for temporary trafficking (with and/or without gritting)
  - validate the amount of tack coat to be used on top of EME2.
- Provide input into benchmarking and mix design specification:
  - based on resilient modulus tests of the production mix at different air voids and loading conditions, provide input into the pavement design process
  - analyse in situ material performance and cross-validate with mix design
  - using the Australian and EN test results provide input into mix design/benchmarking for the national specification framework.
- Long-term monitoring of in situ pavement performance:
  - Network survey vehicle (NSV), including IRI and rutting, reporting to 10 m
  - Falling weight deflectometer (FWD)
    - Between wheel paths (BWP) and outer wheel path (OWP), 5 m staggered (i.e. 10 m in BWP and 10 m in OWP), 50 kN, 3 drops
    - On top of the unbound granular base (if construction staging allows), on top of the upper EME2 layer and on top of the wearing course.

2.4 Tensile Strain versus Allowable Loading for Asphalt Fatigue

Plots of tensile strain against allowable loading to asphalt fatigue are presented in Figure 2.2. This graph is similar to Figure 6.11 in AGPT Part 2 (Austroads 2012); the project reliability is 95%.

The figure indicates the benefits of using EME2; the high bitumen content (by volume) provides improved fatigue resistance, while the asphalt mix modulus remains high (despite of the high binder content). This leads to thinner FDA pavements without compromising the performance. The high performance of the EME2 can be achieve through using a hard penetration grade binder while the mix is balanced through a performance based mix design.

Figure 2.2: Tensile strain versus allowable loading for asphalt fatigue



3 DEVELOPMENT OF EME2 SPECIFICATION LIMITS

3.1 Interim Specification Limits

Interim Western Australian EME2 specification limits were developed based upon the outcomes of research conducted by Austroads and TMR as follows:

- AP-T283-14: *High Modulus High Fatigue Resistance Asphalt (EME2) Technology Transfer* (Austroads 2014).
- TMR (2015) PSTS107: *High Modulus Asphalt (EME2).*
- TMR (2015) TN142: *High Modulus Asphalt (EME2) Pavement Design.*

The limits described in the above documents were developed based upon performance testing carried out by ARRB on a conforming EME2 mix imported from France. An additional two EME2 mixes were tested by Australian asphalt suppliers in their local laboratories using Australian test methods as well as in a European laboratory using French test methods (Austroads 2014).

ARRB contributed to the development of the preliminary Main Roads *Draft Specification 514: High Modulus Asphalt (EME2)* (2016a) and the preliminary Main Roads *Engineering Road Note 13: High Modulus Asphalt (EME2) Mix Design* (2016b). The current interim versions were completed by Main Roads.

The interim Main Roads specifications for the binder used in the design and production of EME2 are summarised in Table 3.1 while the requirements for the combined filler are presented in Table 3.2. Additionally, the EME2 mix design should meet the performance specification limits summarised in Table 3.3.

Table 3.1: Properties of EME2 binder

Property	Method of test	Units	Limits	
			Min	Max
Penetration at 25 °C (100g, 5s)	AS 2341.12	pu (1)	15	25
Softening point	AS 2341.18	°C	56	72
Viscosity at 60 °C (2)	AS/NZS 2341.2	Pa.s	900	–
Loss on heating	AS/NZS 2341.10 or AGPT/T103	%	–	0.5
Retained penetration (3)	AS/NZS 2341.10 and AS 2341.12	%	55	–
Increase in softening point after RTFO treatment (4)	AS/NZS 2341.10 and AS 2341.18	°C	–	8
Viscosity at 135 °C	AS/NZS 2341.2, AS 2341.3, AS/NZS 2341.4 or AGPT/T111	Pa.s	0.6	
Matter insoluble in toluene	AS/NZS 2341.8	% mass	–	1.0
Penetration index	N/A	N/A	Report	
Viscosity at 60 °C after RTFO (2)	AS/NZS 2341.10 and AS/NZS 2341.2	Pa s	Report	
Percent increase in viscosity at 60 °C after RTFO test	AS/NZS 2341.10 and AS/NZS 2341.2	%	Report	

1 One pu equals 0.1 mm.
2 Test shall be performed using an Asphalt Institute viscosity tube.
3 Retained penetration shall be calculated using the equation: (Penetration at 25 °C after RTFO x 100) / (Penetration at 25 °C before RTFO).
4 Increase in softening point after RTFO treatment shall be calculated using the equation: Softening point after RTFO – softening point before RTFO.

Source: Main Roads 2016a.

Table 3.2: Requirements of the combined filler

Property	Method of test	Unit	Mineral filler	
			Min	Max
Voids in dry compacted filler	AS/NZS 1141.17	%	28	45
Delta ring and ball	EN 13179–1: 2000 and AS 2341.18	°C	8	16

Source: Main Roads 2016b.

Table 3.3: Mix design criteria of EME2

Property	Method of test	Unit	Limits	
			Min	Max
Air voids in specimens compacted by gyratory compactor at 100 cycles	AS/NZS 2891.8	%	–	6.0
Stripping potential of asphalt – tensile strength ratio	AGPT/T232	%	80	–
Wheel tracking at 60°C and 30 000 cycles (60 000 passes)	AGPT/T231	mm	–	4.0
Wheel tracking at 60°C and 5 000 cycles (10 000 passes)	AGPT/T231	mm	–	2.0
Flexural stiffness at 50 ± 3 με, 15 °C and 10 Hz	AGPT/T274	MPa	14 000	–
Fatigue resistance at 20 °C, 10 Hz and 1 million cycles	AGPT/T274	με	150	–
Richness modulus	N/A	%	3.4	–

Source: Main Roads 2016a.

Furthermore, EME2 mix designs intended for use in Western Australia must meet the limits described in Table 3.1 to Table 3.3 and be validated in a French laboratory accredited for testing by Comité Français d'Accréditation, in accordance with ERN13.

4 EUROPEAN PRACTICE

High modulus, performance based asphalt mixtures were developed in France with the name EME. French specifications allow the use of two grades of EME, class 1 and class 2. Class 2 (EME2) is a nominal 14 mm in size that utilises stiff bitumen at high contents and is typically used in France for roads subject to heavy traffic loads, airports and for maintenance of deteriorated roads (Fremont et al. 2016). The use of EME2 on arterial roads has resulted in an increase in the permissible maximum axle loading on pavements to 13 tonnes, whereas Australian roads are only permitted to carry 8.5 tonnes, therefore reducing cost of freight per tonne (Distin & Vos 2015).

While EME2 facilitates the provision of strong, durable and sustainable pavements, the performance is only effective in properly designed, constructed and maintained pavement layers. EME2 provides economic benefits and longer service life compared to traditional flexible pavement materials. Additionally, it has greater sustainability, reducing consumption of non-renewable materials such as bitumen and aggregates, minimising the quantities of material transported, increasing design life and decreasing maintenance and traffic disruptions and allowing heaver axle loading, thus reducing greenhouse gas emissions per tonne/km of freight (Distin & Vos 2015).

4.1 Construction

The construction costs of new pavements and the rehabilitation of existing distressed pavements may be reduced by using EME2. This may be achieved by eliminating the need to place a waterproof seal under the wearing course because of the high impermeability of EME2 to moisture, a reduced pavement thicknesses required for equivalent strength and an associated reduction in paving time required to lay the thinner pavements (Distin & Vos 2015).

Transport Scotland's *Introduction of Simplified Design Method for Crack Seat and Overlay (CSO)* (TS 2013) states that construction method for EME layers is the same as conventional materials provided the required temperatures are maintained. Ideally, layers are constructed without cold joints using an echelon paving method but where joints are required for construction reasons, the chamfered edge of the pavement should contain a bitumen tack coat.

Layer thicknesses may be reduced by approximately 25%–30% compared to traditional flexible pavement designs for a given design life. Several precautions are taken during construction of EME2 layers to ensure better performance including maintaining an asphalt plant temperature must be approximately 170–180 °C for sufficient coating of aggregates, a laying temperature of 150–170 °C and a compaction temperature of 140 °C. Furthermore, suitable bonding may require a tack coat and any changes of layer thickness must be incorporated into the design for variation in the load-bearing capacity of the subgrade (Fremont et al. 2016).

The Highways Agency *Specification for Highway Works* (Highways Agency 2008) specifies that the minimum temperature out of the paver for EME2 compaction is 140 °C and shall be completed before the temperature is less than 120 °C. The Highways Agency requires a continual assessment of the compaction using an indirect density gauge, in accordance with BS 594987 (2015), clause 9.4.2 (2015) where the in situ air void content is determined in accordance with EN 12697-8 (2003). Should any six consecutive indirect gauge readings exceed 6% voids, cores shall be taken, and voids determined in accordance with BS 594987, clause 9.5.1.3 (2015). The plant used for compaction shall consist of either:

- steel rollers exceeding 8 tonnes operating weight, provided compaction is speedily undertaken, vibration turned off when traversing compacted material; or
- pneumatic tyred rollers with a minimum weight of 1.0 tonne per wheel, finishing with wide steel non-vibrating rollers and 3-point rollers.

The *French Design Manual for Pavement Structures* (LCPC & Setra 1997) limits the thickness of EME2 layers that may be completed in one pass based on the nominal aggregate size of the mix (0/10 mm, 0/14 mm and 0/20 mm) to 60 to 100 mm, 70 to 120 mm and 100 to 150 mm respectively. The surface that the EME is laid upon must be free from deleterious materials and should be tack coated at a rate of 250 g/m^2 of residual bitumen using emulsion (Sanders & Nunn 2007).

Distin et al. (2008) identified that construction of an EME2 layer should ensure sufficient bond strength is achieved between subsequent layers through the use of a tack coat, the support layer is stiff enough to enable adequate compaction and that EME is protected from significant day/night temperature variation, which may cause thermal cracking. The high binder content and composition contribute to improving the workability and speed of construction of EME2, allowing increased productivity as well as a reduction in construction period and cost (Widyatmoko et al. 2007).

A study conducted by Nicholls et al. (2008) into the performance of pavements incorporating EME2 at five sites in the United Kingdom was undertaken to ensure the anticipated benefits shown by the French are achieved in the UK. Inspection revealed that the air void limits at the joint (≤ 7%) were exceeded in two of the five pavements tested where cores were typically taken in both wheel paths, 25 mm to 150 mm from joints and in the middle of the mat and the voids in accordance with BS EN 12697-8 (2003). However, vacuum repeated load axial test results indicated that low air voids contents (0.8% – 1.1%) may be detrimental to permanent deformation resistance.

It is important to note that EME2 is often combined with a thin high modulus asphalt binder course (Bitumineux Beton Module Élevé, BBME) and a thin asphalt (Béton Bitumineux Très Mince, BBTM) wearing course which provides a high rutting resistance, surface texture and skid resistance while providing additional protection to the EME2 base (Corte 2001).

4.1.1 Pavement Support

In order to enable adequate compaction during construction and provide optimal structural performance, EME2 pavements designed to withstand heavy duty design loading should be designed with consideration of the appropriate minimum supporting conditions.

In French pavement structures heavy duty pavements typically require both a capping layer and a subbase of varying thicknesses and structural requirements, depending on the long-term bearing capacity of the subgrade (as summarised in Table 4.1). Capping layers are typically required to increase the pavement support to 120 MPa, where subgrades with a bearing capacity greater than 120 MPa may not require a capping layer.

Table 4.1: Minimum thickness of unbound granular subbase

Long-term bearing capacity of capping layer and subgrade (MPa)	Minimum thickness of unbound granular subbase (mm)
20 – 50	450
50 – 120	250
120 – 200	150

Source: LCPC & Setra 1997

The United Kingdom Highways Agency pavement foundations are classified into four classes and defined by the stiffness modulus at the uppermost point of the foundation, as summarised in Table 4.2. The Highways Agency pavement design standard, *HD 26/06* (Highways Agency 2006) states that the foundation below an EME2 layer must be class 3, class 4 or a class 2 foundation that has a surface stiffness modulus of at least 120 MPa at construction.

Table 4.2: Foundation classes

Foundation class	Stiffness modulus (MPa)	Minimum thickness (mm)	Notes
1	50 – 100	150	Capping only design without a subbase layer, must not be used for design traffic in excess of 20 million standard axles (msa)
2	100 – 350	150	Subbase and capping design or subbase only design, must not be used for design traffic greater than 80 msa unless minimum 150 mm of bound subbase is used
3	200 – 1000	175	Typically incorporate cement or hydraulically bound mixtures (HBM)
4	400 – 3500	200	Typically incorporate cement or hydraulically bound mixtures (HBM)

Source: Highways Agency 2009

4.2 Maintenance

Maintaining the structural performance of asphalt layers typically represents 50% of the total pavement maintenance expenditure, therefore it is important to balance the initial cost of construction with the proposed maintenance scheme (LCPC & Setra 1997). Table 4.3 outlines the discounted cost of construction and maintenance relative to the proposed maintenance scheme. Maintenance schemes typically involve the removal and replacement of the old bituminous surface course with a new surface course and crack sealing using bitumen emulsions. It is important to note that typically the longer the time between maintenance, the higher the initial investment and as a result, lower discounted cost.

Table 4.3: Typical maintenance schemes for FDA pavements on French national road network varying with traffic

Maintenance intervals	Traffic classes		
	T0	T1	T2
9 years	60% BB 4 cm 40% BB 8 cm	20% ES 40% BB 4 cm 40% BB 8 cm	20% ES 40% BB 4 cm 40% BB 6 cm
17 years	60% BB 4 cm 40% BB 8 cm	20% ES 40% BB 4 cm 40% BB 8 cm	20% ES 40% BB 4 cm 40% BB 6 cm
25 years	60% BB 4 cm 40% BB 8 cm	20% ES 40% BB 4 cm 40% BB 8 cm	20% ES 40% BB 4 cm 40% BB 6 cm
30 years	37% BB 4 cm 25% BB 4 cm	12% ES 25% BB 4 cm 25% BB 8 cm	12% ES 25% BB 4 cm 25% BB 8 cm

Note: BB = bituminous concrete (remove and replace surface course), ES = surface dressing (crack sealing).
Source: LCPC & Setra 1997.

4.3 Findings

The European practice reviewed contain different approaches to the implementation of EME2 technology into asphalt pavements, which may be attributed to differences in local climatic and natural material availability, thus influencing comparisons between requirements. It is important to note that comparisons in practice between Main Roads and the European practice reviewed should undergo careful consideration due to fundamental differences in pavement design practice.

Findings relevant to the implementation of EME2 by Main Roads include:

- achieving the specified air void contents, including longitudinal joints, may eliminate the need for a waterproof seal under the wearing course because of the impermeability of EME2
- ideally, EME2 should be constructed using echelon paving to eliminate cold joints
- maintaining suitable temperatures is important to achieving improved performance:
  - 170–180 °C production temperature at asphalt plant, for satisfactory coating of aggregates
  - 150–170 °C for placing
  - 120–140 °C for compaction
- compacted layer thicknesses constructed in one run should be limited to 70–120 mm for 0/14 mm mixes in accordance with French methodology
- EME2 surface should be tack coated at a rate of at least 250 g/m^2 of residual bitumen using emulsion
- BBME and BBTM wearing courses are often used to provide additional protection to the EME2 base
- the current interim Main Roads *Draft Specification 514* is generally in accordance with European practice

- the support provided by the subbase and/or capping layer below EME2 pavements are required to achieve a modulus of 120 MPa in France and the UK.

5 QUEENSLAND TRIAL

In March 2017, approximately 700 tonnes of EME2 asphalt mix was placed for the Queensland Department of Transport and Main Roads (TMR) project, Gateway Upgrade North in suburban Brisbane.

Main Roads and ARRB personnel carried out a three day visit to Brisbane, Queensland from 8–10 March 2017 with the purpose of overseeing the production and placement of EME2 to transfer knowledge to Main Roads relative to the WA trial. The trip consisted of visits to the trial site, TMR's laboratory, the Boral plant and laboratory, and meetings with some of the stakeholders.

The scope of work completed by ARRB was limited to reporting observations made on site. The scope did not include contract administration and associated interpretation of all available data to assess EME2.

5.1 Pavement Composition of the Trial

The pavement structure for the trial section consisted of a 160 mm thick layer of unbound granular material treated with a cementitious stabilising agent, sealed with Cationic Rapid Setting emulsion grade CRS 60 emulsion with 10 mm aggregate. The design thickness for the EME2 base layer was 110 mm, placed in one layer on top of the working platform seal. A summary of the pavement trial details is presented in Table 5.1.

Table 5.1: Pavement trial details: Gateway Upgrade North, Qld

Material type	Thickness (mm)
Size 14 mm stone mastic asphalt	50
Polymer modified binder seal	10
Size 14 mm dense graded high strength (DGHS) mix	50
Size 14 mm EME2 mix	110
CBS 60 primer seal	10
Improved unbound granular material	160
Subgrade CBR 7%	Semi-infinite
Asphalt thickness	260

The EME2 mix for the trial was manufactured by Boral and verified by TMR.

5.2 Production and Construction

The Boral plant maintained a production rate of 100 tonnes per hour for the EME2, with a production temperature between 180 °C and 190 °C. There were no noted issues with the production of EME2 for the trial.

5.2.1 Paving

Asphalt paving commenced at approximately 10 am on 8 March 2017 and took place in a northbound direction in one layer. Boral utilised one paver and one material transfer vehicle (MTV) to receive the asphalt mix from the trucks and remix it before depositing it into the hopper of the paver (Figure 5.1).

Figure 5.1: MTV during paving operation

5.2.2 Compaction

The compaction of the EME2 mat in the trial was performed using a 9.3 tonne vibrating smooth-drum tandem roller and a 7.7 tonne smooth-drum tandem roller. The temperature of the EME2 mix during compaction was between 160 °C to 170 °C. The rolling pattern could be described in the following manner:

1. two static and two vibratory passes of 9.3 tonne steel double drum roller (Figure 5.2)
2. static back rolling using 7.7 tonne steel drum roller.

It was observed that a static pass of the roller sitting 300 mm from the edge at first pass worked well, followed by a vibratory second pass. Additionally, it was found that for optimum compaction, the roller should be approximately 150 mm from the edge of the asphalt (Figure 5.3). There were no noted issues with temperature loss during compaction of the EME2 mat.

Back rolling using the second, lighter roller does not need to immediately follow the 9.3 tonne roller as back rolling is primarily to achieve a uniform surface finish and remove the 9.3 tonne roller marks (Figure 5.4). It is important to note that Boral did not use the pneumatic multi-tyred roller to achieve the required compaction as Boral's previous experience with EME2 indicated that the use of the multi-tyred roller may lead to bleeding. However, it should be noted that the mat looked coarse (Figure 5.5).

Figure 5.2: Compaction using 9.3 t steel drum roller

Figure 5.3: Steel drum roller sitting 150 mm from edge

Figure 5.4: Back rolling using 7.7 t steel drum roller

Figure 5.5: Finished surface of EME2 after compaction

Source: ARRB.

5.3 Quality Control

Throughout the trial continuous asphalt production testing, material sampling, coring, in situ temperature and density measurement were performed by Boral Asphalt for quality control purposes. However, the results of these tests were not supplied to ARRB.

It is important to note that to ensure correct quality control procedures were followed, TMR personnel attended the trial. Observations and findings of this activity are not provided in the report. TMR mix requirements for daily testing consist of the following four tests:

- particle size distribution (PSD)
- binder content
- maximum density
- compaction tests.

The change in density of the asphalt mat between roller passes was monitored by a nuclear density gauge using the direct transmission method. The density of the mat was measured by taking eight field cores from the compacted EME2 layer, sampled at random locations by Boral.

The cores presented in Figure 5.6 show variations in the layer thickness. The nuclear density gauge results of the compaction show a trial compaction between 97% and 99% maximum density.

Figure 5.6: EME2 sample cores at Boral laboratory for density testing

5.4 Findings

The purpose of the Queensland trial visit was to document the production and placement of EME2 and transfer knowledge to Main Roads to ensure best practice is implemented on the WA trial. The findings show that the EME2 mix was produced, placed and compacted successfully subject to the quality assurance testing. Personal correspondence with TMR indicates that the trial EME2 conformed to the appropriate quality assurance tests and is currently open to traffic.

6 WESTERN AUSTRALIAN TRIAL

The purpose of the WA trial was to assess whether the design mix could be manufactured, placed and compacted to the expected standards using local aggregates and locally-available equipment. A key aspect was to include guidance on construction process with input from expert EME2 practitioners brought over for the trial.

Downer conducted a pre-trial at their Gosnell's asphalt plant yard on 12 April to assist in establishing the required construction processes for the Tonkin Highway trial. The main EME2 trial was conducted on 26 and 27 April at the intersection of Tonkin Highway and Kelvin Road in Perth, Western Australia and was a joint undertaking between Downer Infrastructure, SAMI Bitumen Technologies, Main Roads and ARRB.

The design, preparation, construction monitoring and post-construction testing for the pre-trial and trial have been documented in detail in a WARRIP report for Main Roads, *High Modulus Asphalt (EME2), Tonkin Hwy – Kelvin Road Intersection* (Valenzuela & Latter 2018) and while not contained within this document, is available on the WARRIP website (www.warrip.com.au). The total quantities of EME2 that were produced and placed for the pre-trial and main trial was 100 tonnes and 998 tonnes respectively.

6.1 Knowledge Transfer

Knowledge transfer took place in the form of two workshops as described below.

6.1.1 Tonkin Highway Trial Workshop

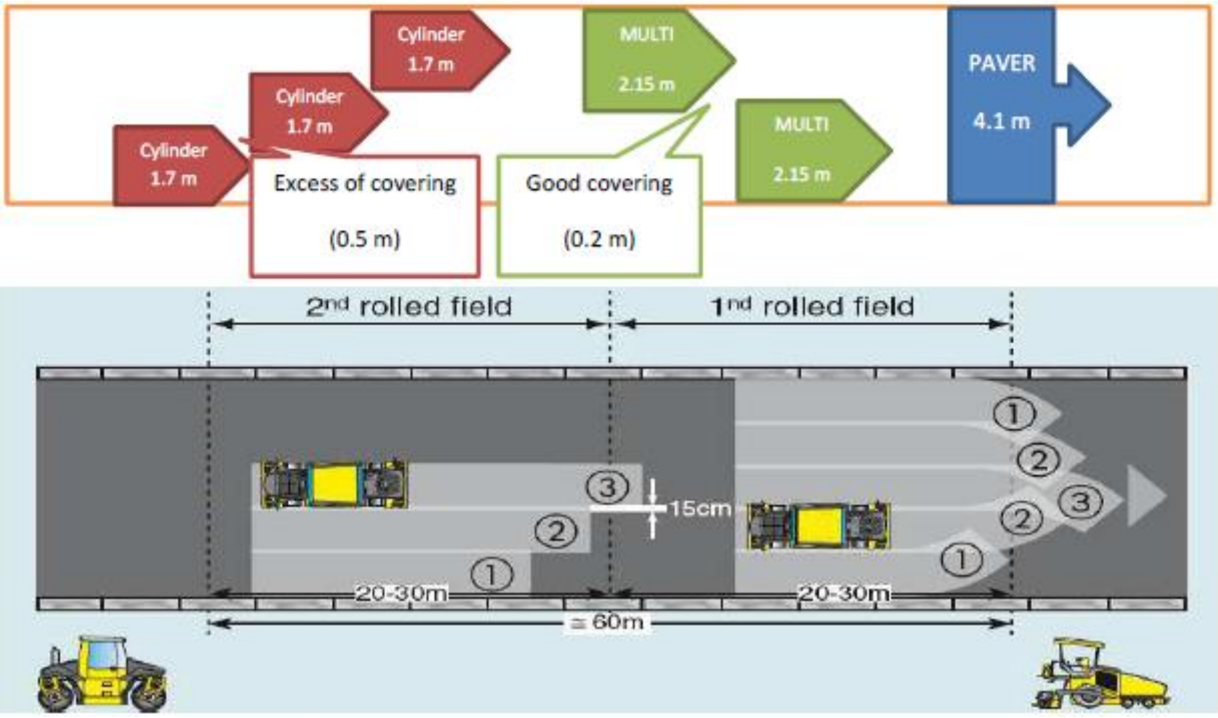
One of the key aspects of the trial was to obtain guidance on the trial installation from a practitioner with extensive EME2 experience. As such, Monsieur Pierrick Dupuy on behalf of Dupuy Conseils, Reunion Island, France attended the Tonkin Hwy trial to provide technical assistance and knowledge transfer for future EME2 projects. Pierrick Dupuy did not identify any significant issues with the construction processes conducted for the EME2 trial but did make several recommendations for improvements to future projects in a report (Dupuy 2017) and a workshop with Downer, Main Roads and ARRB personnel on 28 April 2017. The report is available on the WARRIP website (www.warrip.com.au)

The workshop covered risk management, materials, mix design, specifications, mix design validation of EME2 in the Tonkin Highway trial and improvements for future projects, summarised as follows:

- Ensure a prime coat is applied to the subbase to increase the bond strength between the limestone and EME2 as a lack of bond strength may increase the strains at the interface and decrease the service life of the pavement.
- Use an abrasion resistant thermocouple to monitor the internal temperature of the asphalt behind the paver and ensure the temperature is at least 145 °C for workability.
- Ensure the rolling pattern of the compaction train does not have a high level of overlap (> 300 mm) as this may impact the density variation in the mat, recommendations regarding compaction movements are presented in Figure 6.1. However, it is important to note that French compaction procedures may begin with a multi-tyred roller rather than a steel-drum roller, which may impact the relevance of this recommendation to Main Roads.

- When there is a gap between asphalt supply trucks the operator should reduce the speed of the paver rather than stopping it to guarantee the regularity of the voids in the longitudinal profile. After 20 minutes of inactivity, compaction should be complete and the EME2 must not be over compacted. Plant should be parked away from hot or warm asphalt to avoid rutting.
- Care should be taken to avoid excess compaction and bleeding of the EME2 asphalt, especially when compacting in multiple lifts.
- Tack coat applications are in accordance with NF P 98-150-1 (2010) (Table 6.1).
- Unless the longitudinal joint is constructed using echelon paving (two pavers less than 50 m of separation), the steel drum roller shall overhang the edge of the asphalt by approximately 100 mm.
- Overlap the joint by approximately 30–40 mm and push with a rake to ensure the finer asphalt particles remain close to the surface of the joint (notably, this differs from the practice identified in Section 4.1). Compaction of the joint should begin using a pinch pass of a steel drum roller with approximately 50–200 mm of overlap.

Figure 6.1: Compaction operation



Source: Dupuy 2017.

Table 6.1: Tack coat application rates

Asphalt interface	Tack coat	Bitumen rate	Emulsion
EME2/EME2	Emulsion 60% of 20/30 bitumen	250 g/m²	420 g/m²
EME2/EME2	Emulsion 60% of 35/50 bitumen	250 g/m²	380 g/m²

Source: NFP 98 150-1 (2010).

6.1.2 Asphalt Industry Workshop

On 19 July 2017 a workshop was held by Main Roads and ARRB to present the learnings from the Tonkin Highway trial to the asphalt industry. The workshop covered the following areas, with the key learnings described:

- Tonkin Highway trial planning and mix design:
  - For any project, additional emphasis should be placed on the importance of not exceeding the maximum production temperature of 190 °C.
  - EME2 is a mix with a high dust percentage (± 40%) therefore extreme care should be taken with the dust moisture content as this could affect achieving the desired production temperature. Good practice should cover the dust, especially during winter.
- EME2 pavement design:
  - Design approach is compatible with existing Austroads mechanistic design procedures.
  - The use of EME2 asphalt may save up 10% pavement thickness.
- production and construction:
  - EME2 may generally be constructed like normal DGA.
  - It is recommended that a vertical tank is used for the storage of EME2 binder.
  - Survey levelling should be taken at 5 m intervals.
  - The loose bulking factor shows an increase, compared to DGA.
  - The compaction rollers should stay as close as practicable to the paver, and there should be overlapping of all three rollers.
  - The roller tyres should be kept wet to prevent the lift-up of asphalt mix during compaction. However, the rollers should be taken off the mat if the mix is too hot and mobile. Rollers should not be kept stationary on the mat on the day of paving.
  - Implement joint construction practices identified to produce low air voids, as described in Section 4.1.
  - Coring is to be undertaken the day following paving.
- conformance and research testing:
  - The results show that although the performance testing of the EME2 asphalt mix was generally compliant, there were non-conformances (it is important to note that when the workshop was undertaken performance testing was incomplete).
- future projects that may include EME2 pavements:
  - Kwinana Freeway widening
  - Roe Highway / Kalamunda Road.

7 IMPLEMENTATION TO DATE

The implementation of EME2 technology in Australia has begun in Queensland, Victoria, New South Wales and most recently on the Main Roads trial on Tonkin Hwy. Table 7.1 shows the approximate tonnage of the EME2 laid to date in Australia.

Table 7.1: EME2 implementation in Australia to date

Year	Location	State	Road type	Tonnes (approximate)
2014	Brisbane	Qld	Asphalt plant access road	350
2014	Sunshine Coast	Qld	Quarry access road	350
2015	Perth	WA	Asphalt plant	30
2015	Brisbane	Qld	Industrial collector road	1200
2015	Brisbane	Qld	Industrial collector road	400
2016	Sydney	NSW	Industrial collector road	400
2016	Sydney	NSW	Industrial collector road	400
2016	Brisbane	Qld	Industrial collector road	1050
2016	Brisbane	Qld	Industrial collector road	3530
2017	Brisbane	Qld	Motorway/Highway	10 000
2017	Perth	WA	Asphalt plant	100
2017	Perth	WA	Turning pocket of Tonkin Hwy	1000
			Total	18 810

Source: Adapted from Austroads 2017.

It is important to note that TMR have published MRTS32 *High Modulus Asphalt (EME2)* (TMR 2017) which although similar to Main Roads *Draft Specification 514* (Main Roads 2016a), varies in the following ways:

- combined filler requirements include limit for methylene blue value of 18 mg/g maximum
- binder requirements include limits for a 15/25 penetration EME2 binder as well as 10/20 penetration EME2 binder (Table 7.2)
- includes a maximum asphalt mix temperature of 190 °C for both 10/20 and 15/25 pen EME2 bitumen
- includes in situ air voids requirement in the joint of 8.5% maximum.

Table 7.2: TMR MRTS32 properties of EME2 binder

Property	Method of test	Units	Limit	Value	
				15/25 pen	**10/20 pen**
Penetration at 25 °C (100g, 5s)	AS 2341.12	pu (1)	Minimum Maximum	15 25	10 20
Softening point	AS 2341.18	°C	Minimum Maximum	56 72	59 79
Viscosity at 60 °C (2)	AS/NZS 2341.2	Pa.s	Minimum	900	1050
Loss on heating	AS/NZS 2341.10 or AGPT/T103	%	Maximum	0.5	N/A
Retained penetration (3)	AS/NZS 2341.10 and AS 2341.12	%	Minimum	55	N/A

Property	Method of test	Units	Limit	Value	
				15/25 pen	10/20 pen
Increase in softening point after RTFO treatment (4)	AS/NZS 2341.10 and AS 2341.18	°C	Maximum	8	10
Viscosity at 135 °C	AS/NZS 2341.2, AS 2341.3, AS/NZS 2341.4 or AGPT/T111	Pa.s	Minimum	0.6	0.7
Matter insoluble in toluene	AS/NZS 2341.8	% mass	Maximum	1.0	N/A
Penetration index	N/A	N/A	Report		
Viscosity at 60 °C after RTFO (2)	AS/NZS 2341.10 and AS/NZS 2341.2	Pa s	Report		
Percent increase in viscosity at 60 °C after RTFO test	AS/NZS 2341.10 and AS/NZS 2341.2	%	Report		

1 One pu equals 0.1 mm.
2 Test shall be performed using an Asphalt Institute viscosity tube.
3 Retained penetration shall be calculated using the equation: (Penetration at 25 °C after RTFO x 100) / (Penetration at 25 °C before RTFO).
4 Increase in softening point after RTFO treatment shall be calculated using the equation: Softening point after RTFO – softening point before RTFO.

Source: TMR 2017.

8 RECOMMENDATIONS

8.1 Recommendations from literature and trials

The following sub sections summarise recommendations from the report in general.

8.1.1 European Practice

Findings from European practice relevant to the implementation of EME2 by Main Roads include:

- ensure the mix is maintained at suitable temperatures of at least:
  - 170–180 °C for production
  - 150–170 °C for placing
  - 120–140 °C for compaction
- consider reducing the maximum allowed layer thickness constructed in one run of 0/14 mm EME2 mix from 130 mm to 120 mm to bring in line with French standard
- consider implementing BBME and BBTM wearing courses above EME2 pavement layers
- consider adopting UK practice of an unbound granular improved layer with a minimum design stiffness modulus of 120 MPa below a 150 mm thick bound subbase.

8.1.2 Queensland Trial

The following recommendations, based on learnings in the Queensland trial, for future EME2 projects include:

- EME2 is a mix with a high dust percentage (± 40%) therefore extreme care should be taken with the dust moisture content as this could affect achieving the desired production temperature. Good practice should be to cover the dust stockpile especially during the wet season.
- Discussions should be held with the contractor to set up minimum of requirements for the trial such as, having a nuclear density gauge on site.
- Ensure the trial is continually monitored from commencement and ensure the production and construction crews are aware of the differences between EME2 and AC20 mixtures.

8.1.3 Industry Workshops

Learnings conveyed in a workshop for Downer, Main Roads and ARRB staff covered the risk management, materials, specifications, mix design, mix design validation of EME2 in the Tonkin Highway trial and improvements for future projects. Recommendations from that can be summarised as follows:

- Ensure a prime coat is applied to the subbase to increase the bond strength between the limestone and EME2 as a lack of bond strength may increase the strains at the interface and decrease the service life of the pavement.
- Tack coat applications are in accordance with NF P 98-150-1 (2010) (Table 6.1).
- Overlap the joint by approximately 30–40 mm and push with a rake to ensure the finer asphalt particles remain close to the surface of the joint (notably, this differs from the practice identified in Section 4.1). Compaction of the joint should begin using a pinch pass of a steel drum roller with approximately 50–200 mm of overlap.

A separate workshop was held by Main Roads and ARRB to present the learnings from the Tonkin Highway trial to the asphalt industry. The workshop covered the several areas, with the recommendation under production and construction as follows:

- Survey levelling should be taken at 5 m intervals.
- The compaction rollers should stay as close as practicable to the paver, and there should be overlapping of all three rollers.
- The roller tyres should be kept wet to prevent the lift-up of asphalt mix during compaction. However, the rollers should be taken off the mat if the mix is too hot and mobile. Rollers should not be kept stationary on mix paved on the same day.

8.2 Main Roads Documents

The following sub sections contain recommendations related to specific documents published by Main Roads.

8.2.1 Asphalt Mix Design

It is recommended that Main Roads incorporate a requirement regarding a placement trial before an EME2 mix is approved for use on further works into ERN13 and/or *Draft Specification 514*, as follows:

- Each nominated mix must be subjected to a placement trial. A trial section shall be constructed using the same construction plant, processes and methodology that is proposed to be used for the remainder of the works represented by the trial section.
- A trial section shall be at least 200 m long and 3 m wide so that a longitudinal joint is included. The Contractor must design the trial to implement all operations and testing required by this Specification. The Contractor shall submit a copy of the completed inspection and test plan and all relevant test results and records from the placement trial. Prior to further placement of the Contractor's nominated mix in the works, the Administrator shall review the outcomes of the placement trial. No further works shall be undertaken until Main Roads has given approval to process (Hold Point).
- In the event of a non-conformance in the placement trial, or when Main Roads determines that a previous trial is not representative of the materials, asphalt mix proportions, temperature, plant, rate of output and/or method of placement, a new trial must be undertaken and the Hold Point re-released, prior to full-scale placement resuming.

8.2.2 Pavement Design

It is important to note that ARRB is currently conducting an ongoing project into the update of ERN9 with Main Roads through the WARRIP research agreement and as such, any alterations should be reflected the latest update of ERN9. Recommendations for the inclusion into ERN9 include:

- Typical EME2 pavement structure (Table 8.1).
- Asphalt nominal total thickness, 70 mm minimum, no maximum nominal total thickness.
- Presumptive moduli in accordance with Table 8.2.

Table 8.1: Typical structure of EME2 high modulus asphalt pavements

Course	Description (typical)
Surfacing	10 mm DGA or 14 mm DGA or 10 mm OGA + tack coat + 10 mm DGA
Seal	where specified
EME2 asphalt	14 mm DGA (EME2 asphalt)
Prime	prime
Subbase	unbound granular material (minimum 150 mm thickness) (120 MPa minimum)

Table 8.2: Presumptive moduli for 15/25 pen EME2 mixes for different design speeds at Perth WMAPT

Binder type	Volume of binder (%)	Asphalt modulus at heavy vehicle operating speed (MPa)					
		10 km/h	30 km/h	50 km/h	60 km/h	80 km/h	90 km/h
EME2 (15/25 pen)	13.5	2500	3800	4500	4800	5300	5600

9 SUMMARY

The *High Modulus Asphalt (EME2)* project was undertaken to modify and develop technical guidance regarding Main Roads specifications for EME2 mix design, compaction and placement of asphalt layers for Western Australia in line with the national specification framework. Developing technical guidance was achieved through determining the potential pavement thickness reduction, developing an interim EME2 mix design specification, identifying any barriers to implementation in WA and observing an EME2 trial conducted by personnel in Queensland with experience paving EME2. To ensure the recommended technical best practice was appropriate for WA conditions, a demonstration trial was conducted on Tonkin Highway, in the southbound turning lane onto Kelvin Road. This report also presents details of the Tonkin Highway trial construction and subsequent laboratory testing and results.

It was determined that the potential pavement thickness reductions that may be achieved through the adoption of EME2 technology, relative to the current Main Roads pavement design supplement, ERN9 (2013) ranged from 45 mm to 90 mm. Greater overall asphalt thickness reductions were achieved where all intermediate asphalt layers were substituted with EME2 as opposed to the bottom layer only.

Main Roads has adopted interim specification limits for EME2 asphalt, outlined in *Draft Specification 514: High Modulus Asphalt (EME2)* and *Engineering Road Note 13: High Modulus Asphalt (EME2) Mix Design.* These limits are in line with the national specification framework developed by Austroads (2014). However, it is important to note that the recently published technical specification in Queensland, MRTS32 *High Modulus Asphalt (EME2)* adds several requirements to the national framework which may be of interest to Main Roads.

A review of European practice relative to the design, use, construction and maintenance of EME2 asphalt indicated that there are no significant barriers to EME2 implementation in WA and the current interim specifications adopted by Main Roads are generally in accordance with European practice. Furthermore, differences in the requirements of layers below EME2 between Main Roads and European practice reviewed may be attributed to differences in local climatic conditions, natural material availability and fundamental differences in pavement design methodology.

Ensuring the Main Roads trial was conducted using industry best practice, ARRB and Main Roads personnel attended an EME2 trial in Queensland, as constructed by Boral and overseen by TMR.

It is recommended that Main Roads consider the findings of this project in relation to the revision and finalisation of ERN13, *Draft Specification 514* and ERN9 design procedures for FDA pavements containing EME2. These finding would enable consideration to be given to:

- whether there is sufficient evidence to finalise, and publish *Draft Specification 514,* ERN13 and ERN9 with the suggested changes (Section 8) or whether further trials need to be conducted to ensure the applicability of EME2 technology to WA conditions
- whether the additional requirements outlined in TMR specification MRTS32 have applicability to WA conditions
- developing further amendments to ERN9 and other relevant Main Roads specifications to better reflect the differences between EME2 technology and current DGA mixes utilised by Main Roads
- conducting further investigation regarding whether the application of BBME and/or BBTM mixes above EME2 asphalt is suitable for WA

- regular monitoring of the functional and structural performance of the EME2 trial section on Tonkin Highway to ensure the benefits of EME2 technology are achieved.

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