Implementing EME2, the French high modulus asphalt in Australia

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ABSTRACT

Enrobés à Module Elevé Class 2 (EME2) technology was developed in France in the early 1990's and is now used extensively on main routes, airports and urban roads internationally. Compared to conventional asphalt bases with unmodified binders, high modulus asphalt is characterised by a high stiffness, high durability, superior resistance to permanent deformation and good fatigue resistance. International experience indicates that significant pavement thickness reductions can be achieved using EME2.

Australian road agencies, the asphalt industry and a research organisation (ARRB)together embarked on a project to transfer EME technology to Australia. Some of the Australian national bitumen suppliers are now capable to manufacture and deliver the hard penetration grade binder required in the production of EME2. As a subsequent step asphalt manufacturers developed EME2 mixes in France using EN test methods and specification requirements.

In order to enable implementation of the design philosophy in Australia, Austroads and ARRB delivered a research program on behalf of the Australian state road agencies. The final outcome of the program is a performance based mix design procedure for EME2, which is based on Australian test methods and test conditions. Also, a tentative specification framework for workability, wheel tracking, flexural stiffness, fatigue, and moisture sensitivity were developed for EME2 mixes, which formed the basis of developing specifications by some Australian state road agencies. The requirements for manufacturing, paving and compliance were also provided and validated in a demonstration trial in Queensland, while other trials are planned in New South Wales and Victoria.

The paper describes the development of the specification framework and provides insight into the research methodology for developing specification limits. The paper also summarises the design procedure adopted in Australia. The outcomes are based on extensive performance based laboratory testing which is discussed in details in the paper. The structural and functional performance monitoring of the completed trial pavement, including extensive laboratory testing of the plant produced material is also discussed in the paper. Laboratory and field data collected to date indicates that the EME2 pavement performs as expected.

Keywords: Asphalt, Heavy-duty pavements, Mixture design, Structural fatigue, Technology transfer

1. INTRODUCTION

Enrobés à Module Elevé (EME) technology was developed in France in the early 1990s and is now used extensively on main routes, airports and urban roads internationally. Compared to conventional asphalt bases with unmodified binders, high modulus asphalt is characterised by a high stiffness, high durability, superior resistance to permanent deformation and good fatigue resistance. International experience indicates that significant pavement thickness reductions can be achieved using EME.

Australian road agencies, the asphalt industry and ARRB together embarked on a project to transfer EME Class 2 (EME2) technology to Australia. Some of the Australian national bitumen suppliers are now capable of manufacturing and delivering the hard penetration grade binder required for the production of EME2.

2. DEVELOPMENT OF MIX DESIGN SPECIFICATIONS

2.1 Scope of the research work

The EME2 technology transfer in Australia was launched in 2013 when Austroads funded an explorative study, which provided an insight into the complexity of the design of EME2 mixes. The outcomes of the study were reported in AP-T249-13 [1], which concluded that for a successful technology transfer it is important to select corresponding Australian standardised test methods. This also provided the basis for setting correct performance limits in specifications. Test methods for the binder were readily available; however, test methods for fillers, aggregates and development of EME2 mix performance criteria required substantial work in subsequent projects. As part of the Australian Level 2 mix design system [2] performance-based test methods were readily available. These test methods were similar to those required by the French approach [3,4]; however, they were not identical. In order to develop a nationally agreed specification framework based on Australian test methods, Austroads launched a three-year program. The outcomes of this work, including the development of the Australian mix design specification framework, were recorded in Austroads publication AP-T283 14 [5]. The objectives of the Austroads research can be summarised as follows:

- investigate the mix design methodology of EME2 asphalt mix, based on available international literature
- investigate requirements and local availability of aggregate type, aggregate grading, and hard penetration grade binder
- provide input for implementation of the EME2 technology in Australia
- provide a comprehensive characterisation of EME2 mix using Australian test methods, including workability, moisture sensitivity, rutting resistance, stiffness and fatigue resistance
- develop a tentative specification framework for road agencies for designing EME2 mixes.

Pavement structural design guidelines for pavements containing EME2 were developed by Petho and Bryant [6] and can be found in Technical Note 142 [7].

2.2 Principles of EME2 mix design

The design of EME2 differs from conventional volumetric-type asphalt mix design in that it is strictly performance based. The volumetric properties, such as the air voids (AV), voids in the mineral aggregate (VMA) and voids filled with binder (VFB) of the design mix, are still important in the mix design optimisation phase; however, they do not form specification requirements. In Australia the road agencies and the asphalt industry supported the technology transfer of EME2. EME Class 1 (EME1) was out of scope for the study; in the first phase only the 14 mm nominal (19 mm maximum) aggregate size mix has been utilised.

As part of the research work a specification framework was drafted based on the French methodology, which subsequently went through an extensive development process. The early version of the technical basis of the EME2 mix specification in Australia was used for the first Australian EME2 demonstration trial placed in February 2014 in Eagle Farm, Queensland. Findings from this trial were incorporated into the updated framework and extensively reviewed by the Austroads Asphalt Research Working Group.

2.3 Specification framework – translating the performance requirements

Based on the explorative study [1] it was apparent that the French specification requirements cannot be applied in Australia, due to the differences in the test methods and equipment availability. Therefore a number of mixes were tested using both methodologies, which provided the basis for benchmarking of the mixes, and developing tentative specification limits using Australian test methods. The performance requirements of the mix according to the French methodology were not altered; as discussed in Section 3.2, the requirements for the constituent materials were also kept unchanged. Through this approach it was ensured that mixes designed using the Australian test methods would meet the French specification requirements and there would be no need for lengthy in-service performance evaluation of the material in Australia, since this material has had proven performance in France over the last three decades.

In the technology transfer, comparative testing was performed on the same mix design in France and in Australia. Materials for an existing French EME2 mix were shipped to the ARRB laboratory in Melbourne and the mix was subjected to a series of Australian test methods; the performance of the mix according to the French criteria was well established and known. This series of test results provides an initial set of data for each performance criteria, including workability, moisture sensitivity, wheel tracking, stiffness and fatigue. Meanwhile, various Australian asphalt suppliers sent their material to France for developing EME2 mix designs. Once the designs were completed the mixes were produced locally and subjected to equivalent Australian test methods. This provided a further data set for the benchmarking process and the development of interim specifications.

3. REQUIREMENTS FOR THE CONSTITUENTS AND PERFORMANCE TESTS

3.1 Requirements for the binder

Australian bitumen suppliers are now able to locally produce and supply hard penetration grade binder. The EME binder was a new product in Australia and there were no specification requirements for this material; it was therefore suggested that the EN framework [8] should be applied, tested according to the Australian Standard test methods. Table 1 summarises the final and agreed requirements.

Table 1: Specification requirements for hard paving grade bitumens using Australian Standards and Austroads test methods

Property	Test method	Unit	Limit	Binder 15/25 pen	Binder 10/20 pen
				Value	Value
Penetration at 25 °C	AS 2341.12 [9]	pu(1)	Minimum Maximum	15 25	10 20
Softening point	AS 2341.18 [10]	°C	Minimum Maximum	56.5 72.5	59.5 79.5
Viscosity at 60 °C(2)	AS 2341.2 [11]	Pa.s	Minimum	900	1050
Loss on heating	AGPT-T103 [12]	%	Maximum	0.5	N/A
Retained penetration(3)	AS/NZS 2341.10 [13], AS 2341.12 [9]	%	Minimum	55	N/A
Increase in softening point after RTFO treatment	AS/NZS 2341.10 [13], AS 2341.18 [14]	°C	Maximum	8	10
Viscosity at 135 °C	AS 2341.2 [11], AS 2341.3 [15], AS 2341.4 [16] or AGPT-T111 [17]	Pa.s	Minimum	0.6	0.7
Matter insoluble in toluene	AS 2341.8 [18]	% mass	Maximum	1.0	N/A
Penetration index	N/A	N/A	N/A	Report	Report
Viscosity at 60 °C after RTFO(2)	AS/NZS 2341.10 [13] AS 2341.2 [11]	Pa.s	N/A	Report	Report
Per cent increase in viscosity at 60 °C after RTFO test	AS/NZ 2341.10 [13]	%	N/A	Report	Report

1 One pu equals 0.1 mm.
2 Test shall be performed using an Asphalt Institute viscosity tube.
3 Per cent change in penetration shall be calculated using the equation: (penetration at 25 °C after RTFO x 100) / (penetration at 25 °C before RTFO).

The penetration index (PI) is calculated in accordance with Annex A of EN 13924 [8].

3.2 Requirements for the aggregates and filler

The requirements for coarse and fine aggregate and fillers are directly adopted from the French specifications. These requirements are particle size distribution (PSD), crushed particles, flakiness index and Los Angeles coefficient for coarse aggregate and PSD, aggregate particle density, Rigden voids, methylene blue test, and delta ring and ball test for the filler. These properties have to be tested according to the Australian Standards, except the delta ring and ball test; for the latter there is no equivalent test in Australia and the European test method EN 13179–1 [19] should be used directly. There are no extra requirements for the fine aggregate other than natural sand shall not be used.

3.3 Requirements for the minimum binder content

In Australia the binder film index (BFI) is calculated as a function of the surface area of the aggregates and filler, and the effective binder content. Consideration of the minimum BFI at the volumetric design stage is a guide to the incorporation of sufficient binder in the asphalt mix [2]. Therefore the introduction of the richness modulus (K value), as a design requirement for EME2 mixes, was a straightforward process. For EME2 mixes a minimum K value of 3.4

should be used for establishing the minimum binder content. In Australia the binder content is expressed as percentage of the total asphalt mass and therefore the K value should be calculated as follows:

$$K = \frac{\left(\frac{100B}{100 - B}\right)}{\alpha\sqrt[5]{\Sigma}}$$

where:
B = binder content (% by mass of the total asphalt mix)
$\alpha = 2.65 / \rho_a$
ρ_a = particle density of the combined mineral aggregate determined in accordance with AS/NZS 2891.8 (t/m^3) [20]
$\Sigma = (0.25G + 2.3S + 12s + 150f) / 100$
where:
G = percentage of aggregate particles greater than 6.30 mm
S = percentage of aggregate particles between 6.30 mm and 0.250 mm
s = percentage of aggregate particles between 0.250 mm and 0.075 mm
f = percentage of aggregate particles less than 0.075 mm.
G, S and s may be interpolated using a linear relationship from the grading curve using Australian standard sieves, which differ from the EN sieves.

3.4 Performance tests – workability

In Australia the gyratory compaction is widely used; however, the parameters in test method AS 2891.2.2 [21] relate to a significantly lower contact pressure of 240 kPa. It was decided to use the European settings for gyratory compaction – a vertical loading stress of 600 ±18 kPa, gyratory angle of 0.82 ±0.02 and a rate of gyration of 30 ±0.5 revolutions per minute. In Australia there are two gyratory compactors available, the Gyropac and the Servopac and these settings can be achieved only by the latter, which is more robust.
The workability of the mix is an extremely important part of the mix design; it is to ensure that low in situ air voids contents can be achieved in the field, which provides the longlasting and high performance of the finished layer. The air voids contents were determined directly from the Servopac data (AV%) and from the regression equation v(ng)%. For EME2 mixes the air voids have to be less than 6% (mensuration) at 100 gyratory cycles.

3.5 Performance tests – wheel-tracking

The rut resistance of the mix was assessed using the wheel-tracking test in accordance with Austroads method AGPT-T231 [22], instead of the large wheel-tracking device as required for EME2 in France.
The EME2 working group preferred to retain the current Australian approach, i.e. setting the specification limit by using absolute rut depth in millimetres instead of the proportional rut depth in percentage, as specified by the French standards. The test results were therefore converted into absolute values. The French specification requirement of 7.5% proportional rut depth at 30 000 cycles equals to a 7.5 mm rut depth on a 100 mm slab. The Australian test method requires a 50 mm slab for 14 mm mixes and based on regression analysis the French requirements were converted to 6 mm rut depth when using the Australian test method at 30 000 cycles. This is a significantly higher loading compared to the normal requirement in the Australian test method, which is 10 000 passes (5 000 cycles) at 60 °C.

3.6 Performance tests – moisture sensitivity

The moisture sensitivity of EME2 is assessed in France using the Duriez test (EN 12697-12) [23], while in Australia the modified Lottman test is generally used for this purpose. It was decided that the modified Lottman test, outlined in AGPT-T232 [24] should be used without alteration, with a minimum tensile strength ratio (TSR) requirement of 0.8. The freeze-thaw option is compulsory for EME2 mixes.

3.7 Performance tests – flexural stiffness

The French specifications require performing the flexural stiffness testing according to EN 12697-26 [25], by using the two-point bending testing on trapezoidal specimens. Due to the lack of two-point bending equipment in Australia, fatigue testing was performed using the four-point bending test according to AGPT-T274 [26], except using sinusoidal loading instead of the Haversine loading.
Beams were prepared according to AGPT 220 [27] and they were tested for temperature frequency sweep, using a wide range of frequencies and temperatures of 5-15-25-30 °C. The rationale behind this was that at the early stage of the works it was unclear which temperature should be used for specification limits. As more data was collected it was decided to retain the temperature and frequency value set in the French specifications, therefore a minimum of 14 000

MPa at 15 °C and 10 Hz using the four-point bending equipment was required, which is identical to the French requirements.

3.8 Performance tests – flexural fatigue

The French specifications require performing the fatigue testing at 10 °C, 25 Hz and sinusoidal loading according to EN 12697-24 [28], by using the two-point bending testing on trapezoidal specimens. At the time of commencement of the works, fatigue testing in Australia was in transition after it was confirmed that haversine displacement control testing using the AGPT/T233 [29] protocol in effect results in a sinusoidal strain response of half the intended amplitude [30, 31]. As part of a comprehensive study it was proposed to change the loading mode in the test method from haversine to sinusoidal; works started under the EME2 project confirmed the need for this change in the test method. Findings collected from sinusoidal fatigue testing as part of the EME2 project provided input into the development of the updated test method AGPT/T274 [26].

The fatigue criteria for EME2 using the four-point bending test method at 20 °C, 10 Hz to 50% stiffness reduction requires a minimum of 150 microstrain at 1 million cycles. The utilisation of six specimens at three strain levels and the interpolation of the strain value at 1 million cycles is compulsory.

3.9 Performance tests – design criteria

The mix design criteria using the Australian test methods are summarised in Table 2; the French specification requirements according to the European specifications can be found in NF EN 13108–1 [4]. The background and development of Table 2 is discussed in details in Austroads report AP-T283 14 [5]. In Australia the bulk density of the asphalt specimen is determined using the saturated surface dry (SSD) method and therefore it was decided that specimens prepared for wheel-tracking, flexural stiffness and fatigue should be tested by using the SSD method. Based on a large number of samples prepared and tested for this project it was found that there is an offset of 1.5% between the SSD and mensuration air voids. Therefore specimens prepared for wheel-tracking, flexural stiffness and fatigue should have SSD air voids content of 1.5 to 4.5% compared with the French requirements of 3 to 6%.

Table 2: Mix design criteria for EME2 in Australia

Property	Test method	Unit	Limit	Value
Air voids in specimens compacted by gyratory compactor at 100 cycles	AS/NZS 2891.2.2 [21]	%	Maximum	6
Water sensitivity	AG:PT/T232 [24]	%	Minimum	80
Wheel-tracking at 60 °C and 30 000 cycles (60 000 passes)	AG:PT/231 [22]	mm	Maximum	6.0
Minimum flexural stiffness at 50 ± 3 με, 15 °C and 10 Hz	AG:PT/T274 [26]	MPa	Minimum	14 000
Fatigue resistance	AG:PT/T274 [26] at 20 °C, 10 Hz and 1 million cycles	με	Minimum	150
Richness modulus	N/A	–	Minimum	3.4

4. DEMONSTRATION TRIAL IN QUEENSLAND

Following extensive planning and preparation, the first Australian EME2 demonstration trial was constructed in February 2014 at Cullen Avenue West, Eagle Farm in Queensland. The road section is an access road to an asphalt plant carrying channelised heavy traffic.

4.1 Objectives

The trial had many objectives as follows:

- Develop an interim guideline for designing pavement containing EME2 and develop a plan to enable the evaluation of the performance of EME2 against a standard heavy duty DG20HM asphalt material.
- Assess the feasibility of construction and production of EME2 using asphalt plants and road construction equipment available in Australia.
- Set up long-term monitoring of in situ pavement performance and development of shift factors for pavement structural design and validation of realistic pavement design input values (stiffness and fatigue).

Based on the pavement design study, the following pavement structures were constructed:

- 100 mm thick EME2 base layer, constructed in one paving run
- 150 mm thick EME2 base layer, constructed in one paving run

- 150 mm thick dense graded asphalt for heavy duty application (DG20HM), constructed in two paving runs, as the control section.

4.2 Production control testing

Continuous production tests were performed for the DG20HM control base layer, the EME2 mix and for the wearing course. Testing included PSD, binder content, maximum density, in situ temperature and density measurement, densification of the mat after each roller run measured by the nuclear density gauge, surface evenness, sand patch test, British pendulum testing (BPT) and the SCRIM test; these are discussed in details in Austroads report AP-T283 14 [5]. Functional deterioration (i.e. roughness and rutting) was monitored using ARRB's network survey vehicle.

Thermal segregation and overall temperatures were tested during construction by using a Testo 875-1i thermal imager. Due to the stiffness of the EME2 binder, optimal compaction efficiency is achieved before the mat cools below 145 °C. The paving operation was adjusted according to the observed temperatures by decreasing the gap between the paver and the rollers.

Due to operational and weather constraints, the wearing course was laid after 81 days of base layer construction. The wearing course was an M770 BCC Type 2 10 mm nominal aggregate size asphalt with M1000 multigrade bitumen, with no recycled asphalt pavement added. This is a commonly used mix by Brisbane City Council and would be standard for this type of road. The nominal thickness was 30 mm.

A layer of tack coat was applied to the EME2 and DG20HM surfaces to aid with the application and bond with the new wearing course. The residual binder applied to roads in France on EME2 projects tends to be much higher than standard tack coating in Australia, so the potential impact of this change was of interest during the trial. Anionic slow setting, 60% residual binder emulsion was used. The in situ application rate was checked and the actual residual binder was between 150 and 210 g/m^2; based on cores taken from the finished surface it was apparent that this application rate is safe.

4.2 In situ performance testing

Following the construction, 60 cores were taken over the total road length at six locations. The cut cores were tested for air voids, using both the SSD and mensuration method (Table 3). This test series was conducted in order to collect experience on the offset between the SSD and mensuration air voids; in France the mensuration air voids method is used for EME2, while in Australia it is the SSD method which is normally applied for asphalt mixes.

Table 3: Statistical analysis of the air voids (by mix type)

Location	SSD air voids (%)		Mensuration air voids (%)	
	Average	Standard deviation	Average	Standard deviation
EME2 traffic lanes	0.6	0.3	1.6	0.4
EME2 joint	6.9	1.6	8.3	1.9
DG20HM traffic lanes	5.9	0.8	6.7	1.2

The 150 mm thick (nominal) EME2 layer was cut into lower and upper layers; as expected the lower part had slightly higher air voids, 0.9% (SSD), compared to the upper part, which had an average air voids content of 0.3% (SSD). It was concluded that a high level of in situ compaction was achieved, even with a thick layer of 150 mm. It should be noted that the EME2 layer should be between 70 and 130 mm, and paving of a short, 150 mm thick layer in one run was to test the boundaries of the material.

The wheel-tracking test was performed on the mixes used at the trial by using the small equipment; as per the specification framework, the EME2 mix was tested at 60 °C and 60 000 passes (30 000 cycles). In order to provide a fair comparison all the other mixes were tested using the same parameters. Figure 1 shows that the EME2 mix used at the trial has superior rut resistance.

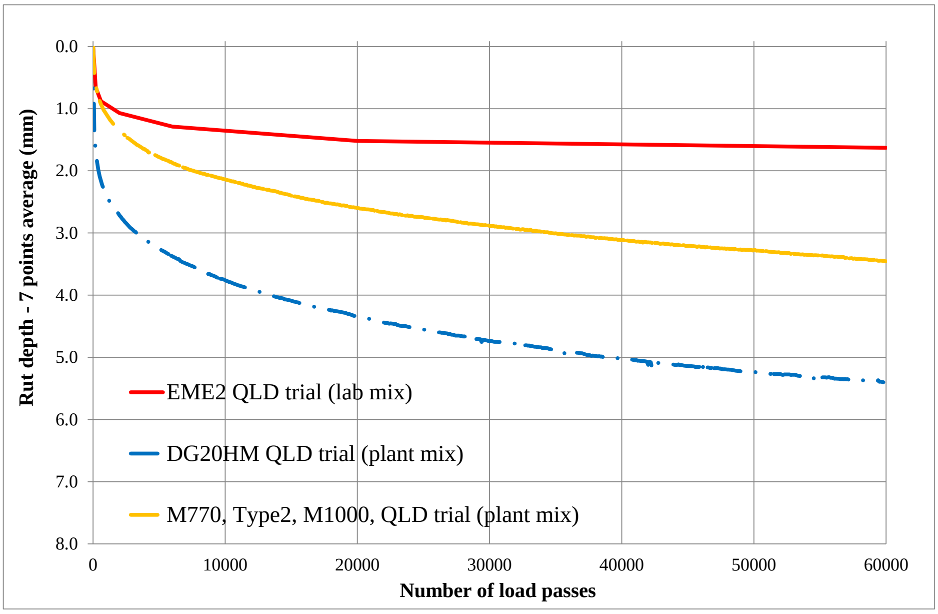

Figure 1: Wheel-tracking (small equipment) test results at 60 °C and 60 000 passes

Flexural modulus tests were performed at 5-15-25-30 °C and a wide range of frequencies between 0.1 and 20 Hz. These test results were used for the construction of the flexural modulus master curves of the different mixes (Figure 2). The EME2 mix shows different characteristics to the DG20HM mix; it has very high flexural modulus at the high temperature or low frequency range, which is desirable in the sub-tropical climatic conditions in Queensland.

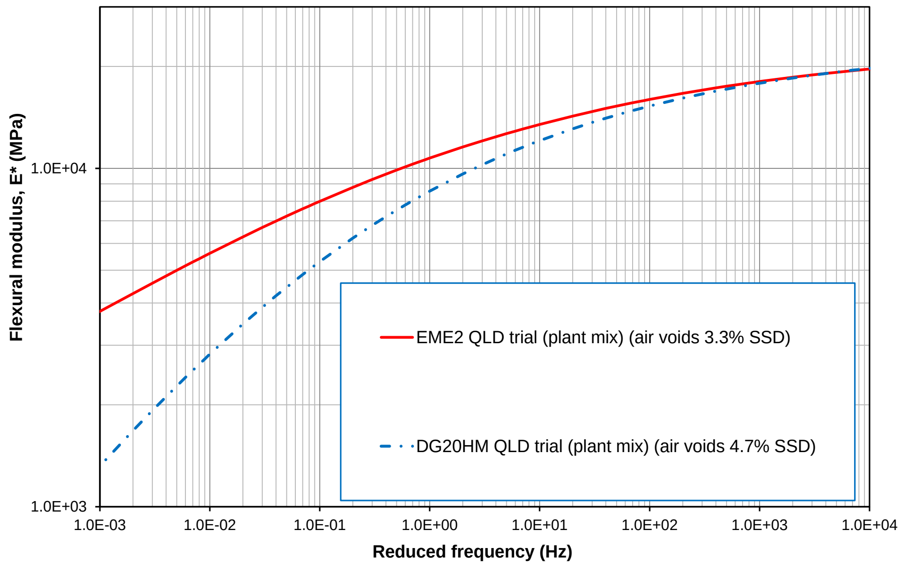

Figure 2: Flexural stiffness master curves of DG20HM control mix and the EME2 trial mix

The flexural fatigue test was carried out at 20 °C and 10 Hz using the four-point bending test method [26] for the DG20HM and the EME2 mix. The fatigue lines, based on testing of 15 beams for the DG20HM mix and 18 beams for the EME2 were constructed (Figure 3) based on regression analysis; the parameters are summarised in Table 4. Although the calculated allowable strains at 1 million cycles are similar for both mixes, there is a significant difference in the slope of the fatigue curve, resulting in a much higher load repetition at low strain levels for the EME2 mix.

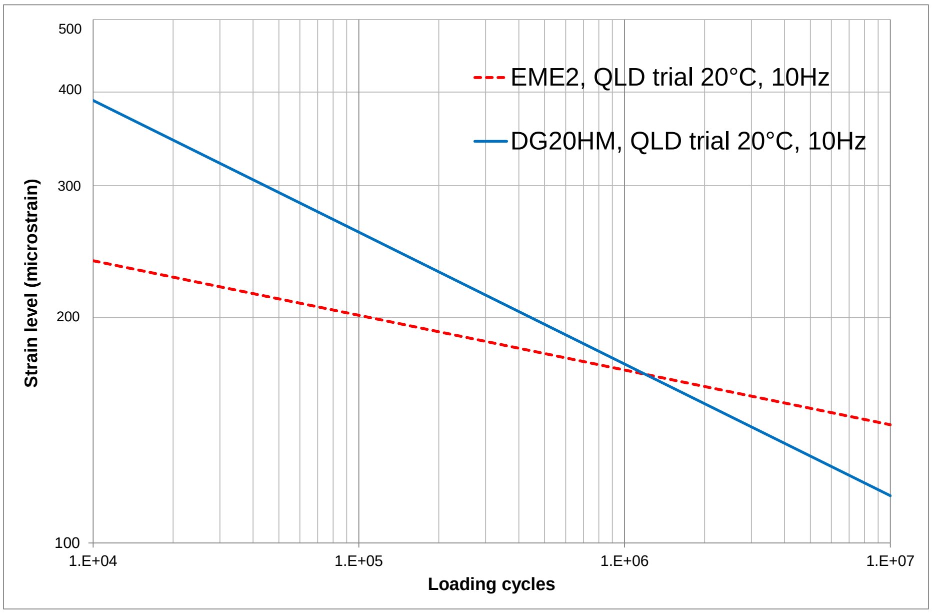

Figure 3: Flexural fatigue of DG20HM control mix and the EME2 trial mix

Table 4: Flexural fatigue test results

Property	EME2, QLD trial	DG20HM, QLD trial
Air voids, average (%)	3.4	target 5 ± 1%
Air voids, standard deviation (%)	0.8	N/A
Correlation equation, constant	466.6	1972.4
Correlation equation, exponent	0.073	0.176
R^2	0.744	0.896
Calculated strain at 1 million cycles	170	173
Slope	-0.073	-0.176
SN (residual standard deviation)	0.26	0.21

5. SUMMARY

The paper summarises the successful EME2 technology transfer to Australia. Based on the delivery of a nationally agreed specification framework, which utilises readily available Australian test equipment and test methods, the performance-based EME2 mix design has been implemented in Australia.
The paper describes the development of the specification framework and provides further insight into the research methodology for developing specification limits. The outcomes are based on extensive performance-based laboratory testing which is discussed in the paper. Laboratory and field data collected to date indicates that the EME2 pavement performs as expected and significant pavement thickness reduction is possible, without compromising the performance.

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