High Modulus Asphalt to Prevent Rutting at Intersections

Dr Greg Arnold[1], Darcy Rogers[1], Simeon Hall[1], Graham Mudgway[1]

1. *Road Science, Mount Maunganui, New Zealand*

ABSTRACT

Pavements at intersections often show shoved and rutted asphalt. A main reason for this is the static and slow loading on the asphalt while heavy vehicles stop at limit lines and traffic lights. Traditional asphalt becomes very soft under static loads and for this reason aircraft stopping areas are often concrete slabs rather than asphalt. A recent example of this was the Te Rapa/Wairere Drive intersection in Hamilton that had 50mm ruts in a 400mm thick asphalt pavement. To repair the rutted areas a special High Modulus Asphalt also referred as EME that uses a very hard binder with a penetration grade of 15/25 was used. This high modulus asphalt was proven to have a 100 times more rut resistance than other mixes trialled when tested in the Repeated Load Triaxial apparatus that simulates slow loading times. The High Modulus Asphalt is also high in binder content to give improved fatigue/crack resistance. This combination of high modulus and improved fatigue can reduce the pavement depth by a third which is an ideal solution for Local Authority urban roads that are constrained by kerb and channel while still being able to resist rutting especially as axle loads are increasing.

Keywords: EME; EME2; High Modulus Asphalt, Asphalt Rutting.

1. INTRODUCTION

EME is a very stiff and high rut resistant structural asphalt mix that was developed in France over 30 years. A recent Austroads project to transfer French Enrobés à Module Élevé Class 2 (EME2) technology to Australia (AP-T283-14) resulted in trials of EME2 in Australia and the development of Queensland TMR EME2 specification (Queensland Transport Main Roads Specification PSTS107 High Modulus Asphalt (EME2)). EME2 has benefits of both very good rut resistance, high modulus and good fatigue life which results in a reduction in thickness along with a benefit of increased rut resistance where heavy vehicles stop or drive slowly at intersections. The potential benefits of EME2 along with the introduction of EME2 in Australia prompted a major contractor in New Zealand whom could make the hard binder required to propose EME2 on a new major State Highway roundabout for NZTA (New Zealand Transport Agency) and the repair of rutting of a major local government intersection. Prior to acceptance of EME2 by NZTA a trial was requested on a local road. For the local government intersection proof was required that replacing the 2 year old structural asphalt with new EME2 asphalt would not rut again. This resulted in Repeated Load Triaxial tests on asphalt cylinders at elevated temperatures and slow loading times for a standard AC mix and polymer modified AC mix along with an EME2 mix being conducted.

This paper reports on the New Zealand EME2 mix designs for Wellington, New Plymouth and Auckland along with results from the trial and laboratory performance tests from insitu cores. Pavement design details of the use of EME2 on a new State Highway project and a heavily trafficked intersection in New Zealand are also summarised. In this report the EME2 mix is referred to as RS EME being the mix naming convention used by Road Science.

2. RS EME MIX DESIGNS

The RS EME binder (15/25 pen) and asphalt mix designs were developed for Wellington, New Plymouth and Auckland in an iterative process to meet the PSTS107 (Queensland TMR) specification for EME2 as shown in Table 1.

TABLE 1 Key Asphalt Mix Design Properties Achieved For RS EME Mixes

Item	*Wellington RS EME*	*New Plymouth RS EME*	*Auckland RS EME*	*TMR PSTS107 EME2 2015*
Total Binder Content (Binder aim to be compliant with PSTS107 EME2)	6.4%	5.9%	6.7%	NA
Binder Penetration at 25 °C *(Note: binder sourced from the same location using the same method)*	20	21	22	15 Min 25 Max
Binder Softening Point °C	72	72	72	56 Min 72 Max
Air Voids (%) @100 cycles	4.9%	4.8%	4.5%	6% max
Void in Mineral Aggregate	18.2%	17.2%	18.7%	NA
Particle Size	Maximum stone size: 13.2 mm	Maximum stone size: 13.2mm	Maximum stone size: 13.2mm	Maximum stone size: 19 mm
Tensile Strength Ratio	81%	93%	98%	80% min.
Wheel Track Rut Depth (@60 degrees for 60,000 cycles)	0.9 mm	0.7 mm	1.0 mm	6.0 max
Flexural Stiffness (15°C, 10 Hz)	12,769 MPa*	11,672 MPa*	9,337 MPa*	14,000 min*
Fatigue Resistance (@ 150 με) – Note: determined from testing 4 beams at a single strain level of 150 με and not from 18 beam specimens and thus not strictly in accordance with PSTS107	>1,000,000 –	>1,000,000	>1,000,000	1,000,000 min.
Reduction in Flexural Stiffness at 10^6 cycles	27%	32%	26%	50%
Richness Modulus	3.8	3.8	4.6	3.4 min.
Resilient Modulus - Matta Modulus (@15°C)	18,100 MPa	17,600 MPa	14,300 MPa	NA

Note: * *The flexural stiffness is below the recommended minimum limit of 14,000 MPa. This lower modulus was taken into account in the pavement design as this lower flexural stiffness does not affect the rut resistance at 60 degrees celcius achieving less than 1mm rut depth.*

The Wellington RS EME matrix structure is shown in Figure 1. This is a fine mix but because of the hard binder used this mix still had exceptional rut resistance with very good fatigue properties.

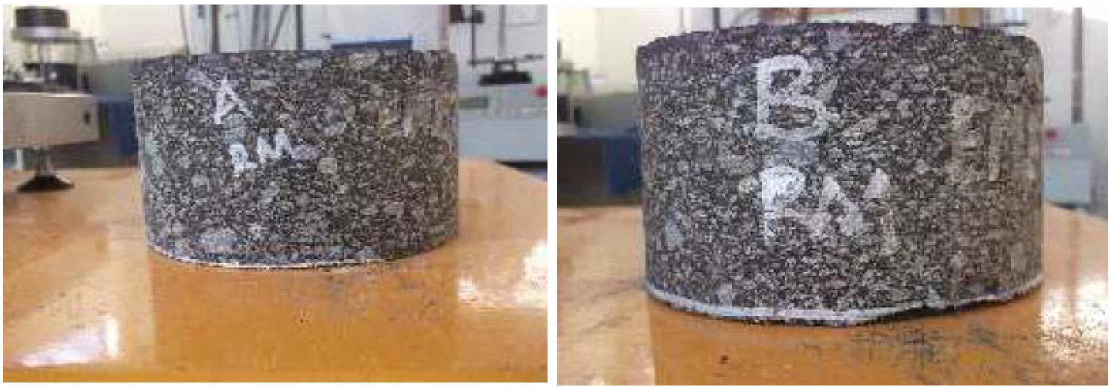


FIGURE 1 Cores taken from the first trial for the Wellington RS EME mix.

3. EFFECT OF SLOW LOADING SPEED AND TEMPERATURE ON RUTTING

Research on the effect on permanent deformation/rutting and compressive modulus/stiffness for a range of asphalt types including RS EME for different loading speeds at three temperatures of 25, 40 and 60 degrees was conducted using the Repeated Load Triaxial apparatus. This study was initiated due to a project requiring replacement asphalt at an intersection in Hamilton which has been repaired often due to ruts reappearing within a year despite using heavy duty asphalt mixes (AC20 with 40/50 or C320 binder) compliant with NZTA M10 specification which is similar to the National Asphalt Specification (AAPA, 2004) for very heavy traffic. At this intersection the existing asphalt thickness is 400mm and the rut depth is greatest (50mm) where the heavy vehicles are stopped at traffic lights often for 10 to 30 seconds.

The Repeated Load Triaxial apparatus was used to simulate vehicle loading at different speeds on compacted asphalt cylinders (150mm diameter by 300mm high) being the same equipment used to evaluate the amount of rutting on unbound granular materials (Arnold, 2004). The temperature was held constant by circulating warmed water around the asphalt cylinders sealed in a latex membrane. This research on asphalt rutting behaviour is ongoing and more recently the water circulation method to increase temperature using external LVDTs to measure strain has been replaced with an environment chamber with internal LVDTs to measure strain (Figure 3). Vertical repeated loading was applied up to 200 loading cycles for different loading speeds from 0.25 second loading speed (4Hz) up to 30 seconds of loading time. The permanent strain rate was calculated from the slope of permanent strain from 100 to 200 load cycles. This permanent strain rate is then extrapolated linearly to estimate the number of load cycles to reach a rut depth/permanent strain value considered failure. It has been recognised that there are inaccuracies of this approach, given the permanent strain slope changes with increasing load cycles beyond the 200 tested as shown in Figure 2. Thus results in this paper are for comparative purposes only and do not necessarily reflect actual lives in the pavement. This research is continuing with Repeated Load Triaxial tests on asphalt mixes for 50,000 load cycles on each loading stage for a more accurate prediction.

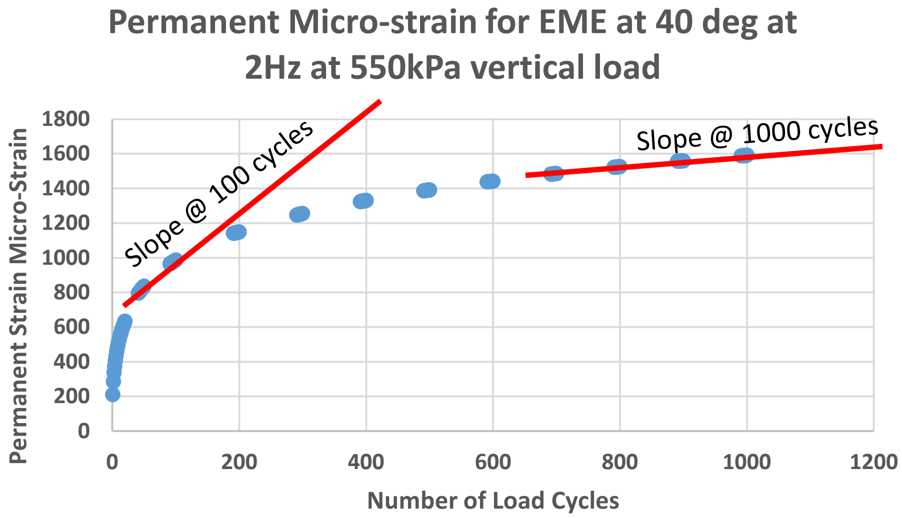


FIGURE 2 Permanent Strain Measured on RS EME mix up to 1000 cycles in the Repeated Load Triaxial Test.

The Repeated Load Triaxial test reports both resilient vertical modulus being vertical stress divided by recoverable elastic strain and permanent strain (Figure 2) being a measure of how much the sample is getting shorter/compressed (ie. a measure of the non recoverable strain). Resilient modulus results at 40 degrees celcius at different loading speeds are shown in Figure 5. The modulus values for the PMB AC was the same as the standard AC, however the amount of non-recoverable or permanent strain was one-tenth the standard AC which is used in the calculation of rutting life as shown in Figure 6. Further, the PMB AC sample did not fail after the test as did the standard AC (Figure 4) indicating superior performance for the PMB AC. For both modulus and permanent strain with predicted rutting life the RS EME mix was superior to both the PMB AC and standard AC mixes (Figure 5 and 6).

Despite the potential inaccuracies of the RLT testing where external LVDTs were used and only 200 load cycles were applied for each combination of loading temperature and times this initial testing resulted in a significant difference in the results on permanent strain for a standard AC20 mix, PMB AC20 mix and a RS EME mix. The standard AC20 mix had 100 times more permanent strain than the RS EME mix and the sample failed after applying 200 load cycles for a 30 second load pulse time at 40 degrees celcius (Figure 4). Conversely, the RS EME mix did not fail the 30 second load pulse time at 40 degrees and failure did not occur when repeating the testing at 60 degrees for the RS EME mix. A polymer modified (PMB) AC20 was also tested with results for all three different structural asphalt mixes (AC20, PMB AC20 and RS EME) shown in Figure 5 and 6 for 40 degrees celcius. Results show the modulus and rutting life reduces for all mixes with increasing loading times. The RS EME is estimated to achieve 100 times the rutting life of the AC20 for 10 second loading times or greater, while the PMB AC20 achieved 10 times the rutting life (Figure 6). This initial study showed the RS EME mix is the best performer in terms of rut resistance at slow and stationary heavy loads and is the best mix for locations at traffic lights, bus stops and airports where heavy vehicles stop for short periods of time.

This difference in rutting performance can be partly explained by the viscosity of the RS EME and 40/50 penetration grade binder. The viscosity of the RS EME binder at 60 degrees was determined to be >2000 Pas (note equipment used could not measure >2000 Pas) while the viscosity for the 40/50 penetration grade binder is 330 and thus at least 6 times more “thinner”.

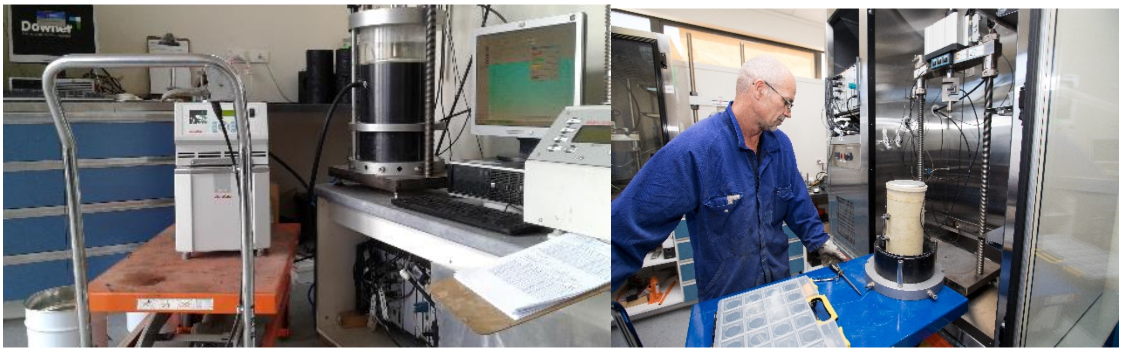


FIGURE 3 Repeated Load Triaxial Setup on Asphalt Cylinder using circulating water to increase temperature (note this was early testing and an environment chamber/oven now houses the triaxial cell).

FIGURE 4 Repeated Load Triaxial Test result on AC20 with 40/50 binder Asphalt Cylinder at 40 degrees celcius after 200 cycles for a 30 second haversine load pulse (vertical load of 550kPa).

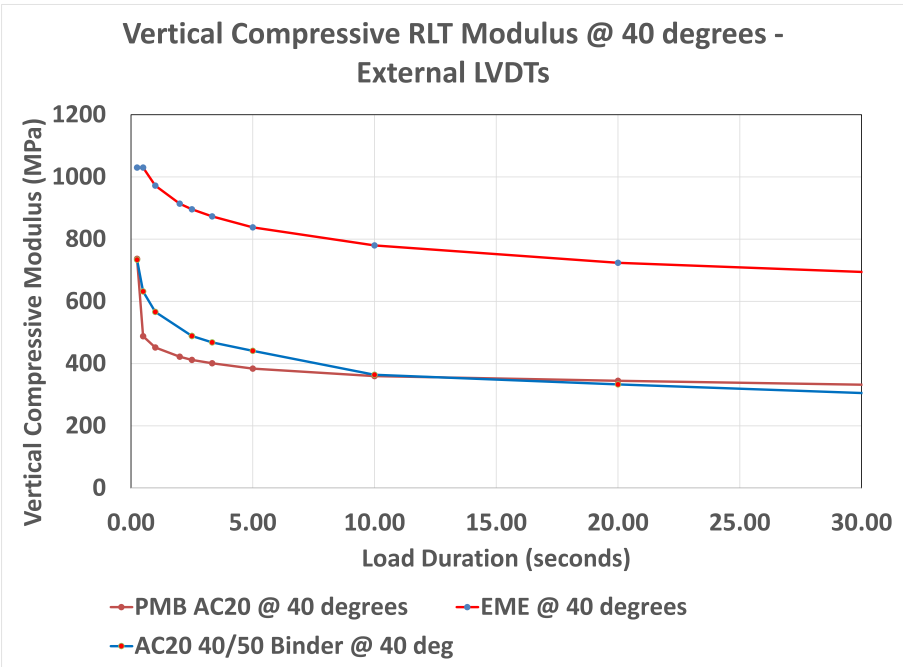


FIGURE 5 Repeated Load Triaxial Vertical Compressive Modulus *(note: despite the PMB AC20 resulting in the same modulus as the standard AC20 the PMB AC20 had better rut resistance as shown in Figure 6)***.**

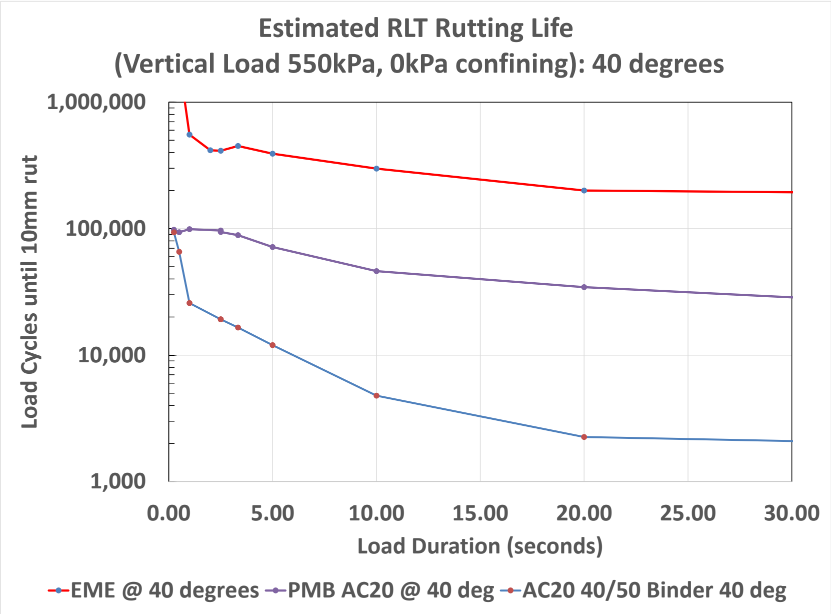


FIGURE 6 Repeated Load Triaxial Rutting Life Prediction.

It should be noted that alternative binders like EVA and fuel resistant polymers when added to asphalt mixes will also improve rut resistance which can be quantified by the Repeated Load Triaxial test at a design load duration and temperature. Figure 6 shows a PMB AC20 which is approximately 5% SBS showed a tenth of the rutting compared with the neat AC20 with 40/50 binder although the EME mix was superior at these slow loading times found at intersections.

4. RS EME PROJECTS

Several sites have recently used RS EME mixes as summarised in Table 2. These sites are heavily trafficked intersections and a taxiway at the airport. The Hamilton and airport sites were at locations of stopped heavy vehicles and planes where the standard structural asphalt pavements have rutted earlier than expected. This early rutting failure with standard asphalt was predicted in the Repeated Load Triaxial study simulating slow loading times as that occurs at intersections as shown in the previous section. Conversely the RS EME mix showed good performance at slow loading speeds simulated in the Repeated Load Triaxial testing which prompted its recent use on several sites as detailed in Table 2.

TABLE 2 Projects where Wellington RS EME Mix was used.

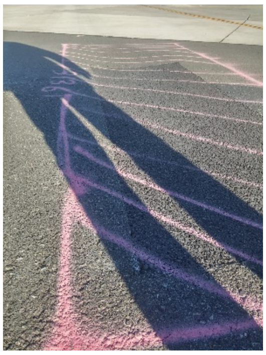
	Wellington RS EME MIX SITE DETAILS	
Site	***Existing Site Characteristics***	***Post-construction***
Wellington RS EME Mix – Site 1 – Aotea Quay Intersection	 AADT = 30,000; HCVs = 15% (Equates to 25 year design loading of 33 Million ESA) Right and left turning areas into Toll and Mainfrieght transport depots have rutted.	 50mm AC surface over 100mm Wellington RS EME Nil distress 10 months trafficking
Wellington RS EME Mix – Site 2 – Wellington airport hardstand and taxiway trial	 Photo shows 6 month old AC14 with heavily rutted areasat Wellington airport prior to repair with Wellington RS EME	 50mm AC surface over 150mm Wellington RS EME (site close to terminal) 200mm Wellington RS EME (site with plane shown) Nil distress 6 months after aircraft loading
Wellington RS EME Mix – Site 3 – SH2/SH58 Interchange Roundabout	 Greenfields site. Design loading over 25 years is 14 Million ESAs (Equivalent Standard Axles),	 50mm AC surface over 130mm Wellington RS EME (on roundabout section) Nil distress 3 months of construction traffic

TABLE 3 Projects where Auckland and New Plymouth RS EME Mix was used.

	Auckland and New Plymouth RS EME MIX SITE DETAILS	
Site	***Existing Site Characteristics***	***Post-construction***
Auckland RS EME Mix – Site 1 – TeRapa/Wairere Road Intersection, Hamilton	  Prior to repair with RS EME a heavily rutted intersection. Cores showed existing total asphalt thickness is 400mm. AADT = 9,671; HCVs = 7.1% 6.7 MESA 25 year design traffic	 Mill out 150mm of existing asphalt and replaced with 50mm AC surface over 100mm RS EME. Nil distress 1 month after construction.
New Plymouth RS EME Mix – Site 1 – SH3, New Plymouth	  Prior to repair with RS EME the road had rutted and cracked. AADT = 32,221; HCV=5% 16 MESA (25 year design traffic)	Constructed 7th May 2017. Design is 50mm AC surface over 130mm New Plymouth RS EME. 

4.1 Results - Modulus Testing

Resilient modulus (or MATTA) testing has been carried out on 150 mm diameter cored specimens. Testing has been carried out on plant mix, and field cores in some cases at 15°C and 25°C. Testing was carried out using the method AS/NS 2891.13.1 – 13.

The results are summarised in the table below.

TABLE 4 MATTA (Resilient) Stiffness Testing Results

		MATTA MODULUS (MPa)		
Mix Production Location	Testing Temperature	Wellington RS EME	New Plymouth RS EME	Auckland RS EME
Laboratory Design	15°C	18,100 MPa	17,600 MPa	14,300 MPa
	25°C	Not tested	11,200 MPa	Not tested
EME sampled from the plant	15°C	18,500 MPa	Mix not used	13,400 MPa
	25°C	13,600 MPa	Mix not used	8,200 MPa
Insitu Cores (Road Science Measured)	15°C	9,900 MPa	Mix not used	7,500 MPa
	25°C	5,000 MPa	Mix not used	3,200 MPa

In addition, flexural modulus was also carried out on beams made from the laboratory mix design as well as the plant produced mix during construction. Testing was carried out using the method AG:PT/T274 – 16. The RS EME sampled from the plant gave similar flexural beam modulus values as in the laboratory design.

TABLE 5 Flexural (beam) Stiffness Testing Results

		Flexural Beam Modulus (MPa)		
Mix Production Location	Testing Temperature	Wellington RS EME	New Plymouth RS EME	Auckland RS EME
Laboratory Design	20°C	10,000	9,300	7,100
	15°C	12,769	11,672	9,337
RS EME sampled from the plant	20°C	8,400	n/a	7,600
	15°C	11,369	n/a	n/a

4.2 Results - Wheel Tracking

The wheel tracking test is an accelerated rutting test at 60 degrees celcius to give an indication of the deformation resistance of the asphalt mixture. This test is carried out according to AG: PT/T231. According to NZTA M/10 specification, a Heavy mix should have a deformation of 6 mm or less at 10,000 passes, and accordingly the Queensland TMR Specification 2015 (PSTS107), there should be a deformation resistance of less than 6.0 mm at 60,000 passes. The results are summarised in the table below.

TABLE 6 Wheel Tracking Results on field cores

		Wheel Track Rutting at 60 degrees for 60,000 cycles (mm)		
Mix Production Location	Testing Temperature	Wellington RS EME	New Plymouth RS EME	Auckland RS EME
Laboratory Design	60°C	0.9	0.7	1.0
EME Plant Mix	60°C	1.6	n/a	n/a
Insitu Cores	60°C	3.2	n/a	n/a

4.3 Results - Fatigue Testing

Fatigue testing was carried out on beams made from the laboratory mix design as well as the plant produced mix during construction. As per the TMR specification (PSTS107), a minimum 1 million cycles must be endured with the following testing conditions: 150 microstrains (sinusoidal loading which is the same as 300 microstrains at haversine loading), at 20°C, and at 10 Hz. The test shall be in accordance with AG:PT/274.

As in the table below, the asphalt mix, including plant produced mix can endure at least 1,000,000 load cycles at 150 microstrains with generally only around 30% reduction in stiffness.

TABLE 7 Fatigue Testing Results (150 micro-strain sinusoidal loading being the earlier 300 micro-strain at haversine loading)

		Flexural Beam Fatigue 1 Million Cycles Applied @ 150 micro-strain sinusoidal loading					
Mix Production Location	*Testing Temp*	*Wellington RS EME*		*New Plymouth RS EME*		*Auckland RS EME*	
		Stiffness Re-duction	*Start Modulus (MPa)*	*Stiffness Re-duction*	*Start Modulus (MPa)*	*Stiffness Re-duction*	*Start Modulus (MPa)*
Laboratory Design	20°C	27%	10,000	32	9,300	26	7,100
EME sampled from the plant	20°C	25%	8,400	n/a	n/a	26	7,600

4.3 Results Discussion

The modulus results (MATTA and Flexural Beam) were similar for both lab mix design and from plant mix. Although, the flexural beam modulus at 15 degrees ranged from approximately 9,000 to 13,000 MPa which is below the Queensland TMR specification requirement for 14,000 MPa. In addition, Matta modulus on insitu cores resulted in values half those obtained in the lab made cores. This halving of modulus is due to less confinement of the compacted asphalt in the road compared with the confinement from the steel mould when compacted in the servopac (Saleh, 2008). The Austroads Pavement Design method does not require modulus values from insitu cores but uses modulus values from lab manufactured cores. Despite this the lower modulus values for the Wellington RS EME mix was used in pavement design resulting in an extra 30mm in thickness when compared with using lab mix modulus values. The client and peer review Engineers were comfortable with the use of RS EME mixes and design approach with the lower modulus given the very good rut resistance shown in the wheel tracker and Repeated Load Triaxial test (Section 3).

5. CONCLUSIONS

RS EME mix compliant with Queensland TMR EME2 specification PSTS107 with the exception of modulus, is now the mix to choose for heavy trafficked intersections where vehicles stop. This is because standard asphalt used at intersections was rutting prematurely and to repair these sites a more rut resistance asphalt was required. A limitation of current pavement design practice is there is no method to predict the rutting life/amount in an asphalt layer for a known speed of loading and temperature which is important for intersections with stationary heavy vehicles. This research found the Repeated Load Triaxial test has potential to predict rutting at slow loading speeds.

RS EME mixes were proven to be more rut resistance when compared with an AC20 and PMB AC20. This was proven in the Repeated Load Triaxial testing simulating slow loading times. Research on Repeated Load Triaxial testing of asphalt samples is continuing by conducting tests at a greater number of load cycles of up to 50,000 at a greater number of loading times and temperatures. The aim is to develop a rut depth prediction model for asphalt based on master curve theory for any combination of vertical compressive strain, temperature and loading speed which will result in a compressive strain criterion to predict rutting life for use in the CIRCLY pavement design software. This will be a significant step change in the design of structural asphalt pavements at intersections, ports and airports where a majority of structural asphalt is used in New Zealand.

This paper also details several sites where RS EME mix was used and these sites are less than a year old. Thus it is recommended that the performance of these sites be monitored and reported at future conferences along with the more detailed Repeated Load Triaxial study of RS EME mixes.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

[1] AAPA. 2004. National Asphalt Specification.
[2] Austroads. 2014. High Modulus High Fatigue Resistance Asphalt (EME2) Technology Transfer. Austroads Technical Report AP-T283-14. Sydney, Australia.
[3] Arnold. G. 2004. Rutting of Granular Pavements. PhD Thesis. University of Nottingham, UK.
[4] QTMR. 2015. Queensland Transport and Main Roads Specifications PSTS107 High Modulus Asphalt (EME2). May 2015.
[5] Saleh, M. 2008. Hot Mix Asphalt Stiffness Moduli: Laboratory versus Field. Sapporo, Japan: 6th International Conference on Road and Airfield Pavement Technology, 20-23 Jul 2008.