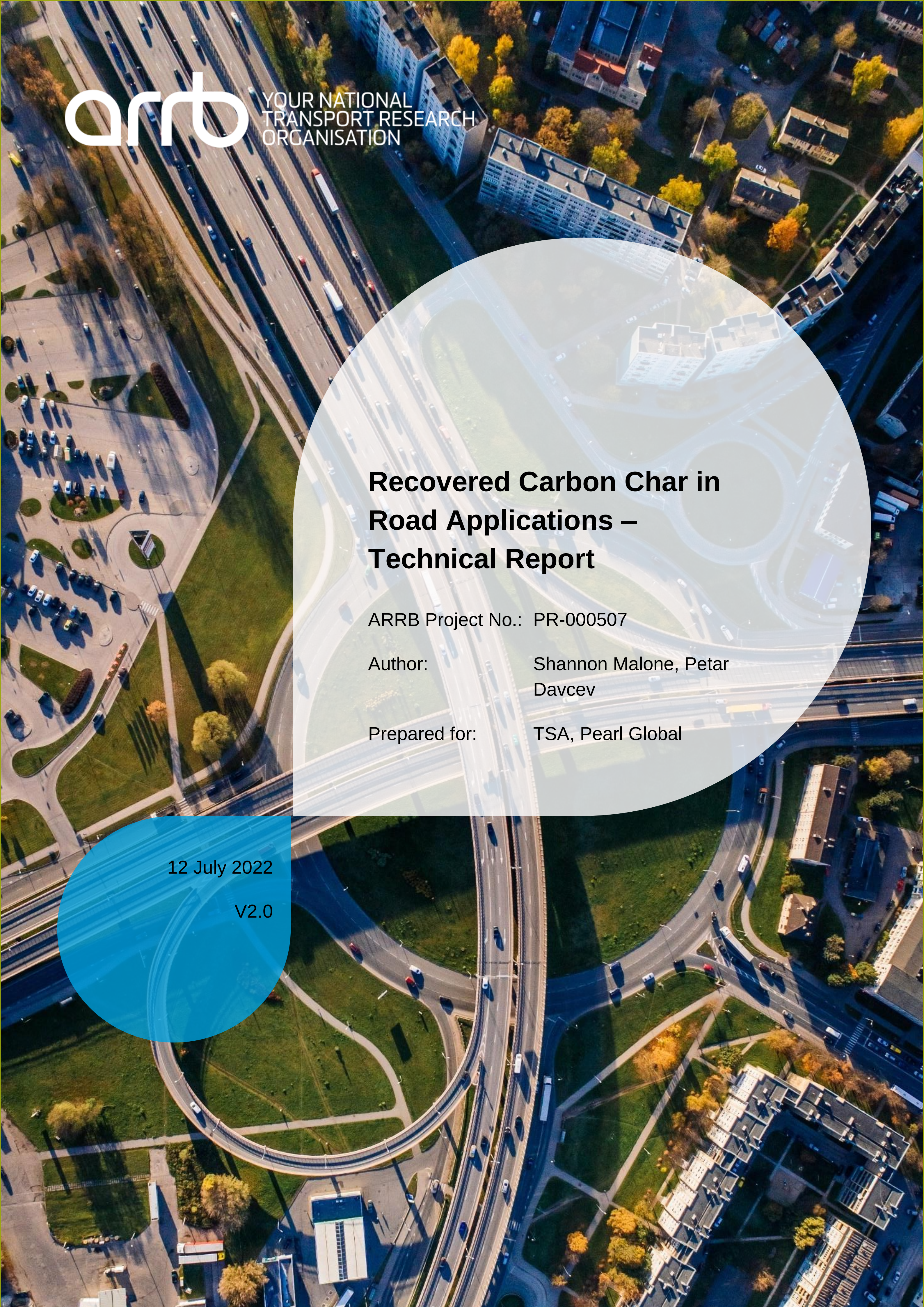

YOUR NATIONAL TRANSPORT RESEARCH ORGANISATION

Recovered Carbon Char in Road Applications – Technical Report

ARRB Project No.: PR-000507

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Prepared for: TSA, Pearl Global

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V2.0

Summary

ARRB's national research laboratory conducted the laboratory testing as described in the project plan. The results of which are tabulated in this report. Furthermore, the results of a plant trial, which was laid in Logan City Council (which contain an equivalent amount of carbon char) was added to the tabulated results to investigate the impact on aging on performance of the asphalt.

rCB addition to asphalt has the potential to improve both deformation resistance in the high temperature region and crack resistance in the low-temperature region, rCB is an effective filler for improving the durability of asphalt pavements. The addition of a rCB recycled material to market would give contractors bidding on infrastructure projects access to another materials option which has the benefit of being recycled, and potentially performance improving.

Based on the material properties of the carbon char product, it is theorised that the rCB would be a suitable replacement for the mineral filler, as well as a potential performance improver. As part of the process to assess the carbon char material, the testing plan is detailed: - Volumetrics - Resilient modulus - Stripping potential (moisture sensitivity) - Deformation resistance - Stability of asphalt (Hamburg) - Flexural stiffness (4x beams and 4x temperature) - Fatigue resistance (9x beams and 1x temperature). The results of the trial will be interpreted and elaborated upon in the proceeding final technical report.

The addition of rCB to laboratory manufactured asphalt mix did not have a significant detrimental impact to the performance when compared to the control asphalt mix. The addition of rCB increased the resilient modulus, the tensile strength stripping potential (moisture sensitivity) of the dry and wet (freeze thaw) subsets, the stability of asphalt (Hamburg) and the fatigue life. The rCB laboratory manufactured asphalt at the completion of stability of asphalt (Hamburg) testing was visually blacker when compared to the control asphalt

The addition of rCB to laboratory manufactured asphalt mix complied with the requirements of TMR technical specification MRTS30 – Asphalt Pavements.

The addition of rCB to plant manufactured asphalt mix did not have a significant detrimental impact to the performance when compared to the control asphalt mix. The addition of rCB increased the performance of the flexural stiffness and had and showed a significant improvement of the fatigue life due to aging (i.e. the performance characteristics indicate that they would improve overtime).

Acknowledgements

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1. Introduction

This report presents the results of the laboratory assessment of incorporating the recovered carbon char material into asphalt applications. This assessment is compared to a control mix with no carbon char, as well as reviews the impact of aging on performance of the asphalt supplied for in-field trials conducted by Austek, Pearl Global and Logan City Council.

1.1 Background

ARRB has come together in partnership with Pearl Global to propose a laboratory program to test the viability and performance of the recovered carbon black (rCB) also known as carbon char product produced by Pearl Global. The carbon char is a by-product from the patented and unique recycled tyre desorption process and can be used as an additive in various new products, including in asphalt. Pearl Global utilises an innovative desorption technique to produce carbon char from recycled tyres which results in a high percentage of active carbon black in the recovered char.

In this project, ARRB has proposed a comprehensive laboratory program that will utilise this by-product as an addition to a regular asphalt. The rCB can be classified as a mineral filler where used in asphalt are defined as the portion of the aggregate mixture that passes the 0.075 mm Australian Standard sieve. These fillers can either comprise the fines component from natural aggregates used in the asphalt mix or be added from an external source. Commonly used fillers include baghouse dust extracted from the asphalt plant, hydrated lime, Portland cement, cement kiln dust, ground limestone, ground slag and fly ash.

The laboratory program consisted of two components; manufacturing of asphalt in ARRB's laboratory from raw materials and review of the performance properties of asphalt manufactured in ARRB's laboratory from asphalt plant mix.

The materials used in the study were representative samples of the aggregate stockpiles and asphalt plant production used to supply Logan City Council sustainable asphalt surfacing project, funded by Tyre Stewardship Australia (TSA).

The rCB asphalt mix was manufactured by using the same asphalt mix design proportions as the control asphalt mix and replacing 1 % of the dust fraction with 1 % of rCB.

The projects laboratory program for the rCB material will ensure dissemination of the results of the research at critical stages will support the increased use of rCB in both government and industry. Local governments, state road agencies and the asphalt and bitumen industries are considered key stakeholders in this project and their input may potentially be sought throughout the project.

1.2 Project scope

The scope of this project is to undertake a material assessment for filler type replacement utilising the carbon char as the replacement material. Based on the initial consultation between ARRB and TSA the proposed scope was agreed and is detailed in Table 1.1 below:

Table 1.1: Scope of work for this project Testing summary Scope of work for this project

Tasks	Description of work required to achieve Task	Achievement date	Required Evidence of achievement
Inception	Inception, Meetings, Project Management, Dissemination Presentations	Jan, 2022	Meeting minutes and project plan.
Procurement of Materials	Collecting, storing, processing, preparing sampling, documenting and sourcing materials.	Jan, 2022	Communication and documentations of delivery of materials.
Laboratory Testing	Comprehensive laboratory program to assess the carbon char material.	May, 2022	Laboratory Testing results shared in testing report.
Technical Analysis	ARRB experts will interpret the results and produce a relevant, technically sound report detailing the results.	Jun, 2022	Results shared in final technical report.

The laboratory testing is summarised in Table 1.2 below.

Table 1.2: Testing summary

Tasks	Test methods
Volumetrics • Compaction at 150 °C • 50 Marshall blows • Maximum density • Bulk density • Air voids	AS/NZS 2891.5 AS/NZS 2891.7.1 AS/NZS 2891.8 AS/NZS 2891.9.2
Resilient modulus	AS/NZS 2891.13.1
Stripping potential (moisture sensitivity)	AGPT/T232
Deformation resistance	AGPT/T231

Table 1.2: Testing summary continued

Tasks	Test methods
Stability of asphalt (Hamburg)	TMR Q325

Flexural stiffness
• Four beams
• Five temperatures
  ○ 5 °C, 10 °C, 20 °C and 30°C
• Eight frequencies
  ○ 0.1, 0.5 Hz, 1.0 Hz, 3.0 Hz, 5.0 Hz, 10.0 Hz, 20 Hz and 30 Hz
	AGPT/T274

Flexural life
• Nine beams
• One temperature
  ○ 20 °C
• Minimum of three strain levels
  ○ High, medium and low
	AGPT/T274

2. Test results

2.1 Recovered Carbon Char test summary using raw materials – laboratory mix

The comparison of the properties of asphalt specimens manufactured from raw materials using the asphalt mix design proportions provided by Austek that were used in the Logan City Council project are shown below.

Table 2.1: Laboratory volumetric test results

Testing Summary		Control Asphalt	rCB Asphalt	TMR MRTS30
Volumetrics	Average maximum density (t/m^3)	2.519	2.502	-
	Average bulk density (t/m^3)	2.405	2.391	-
	Average air voids (%)	4.5	4.4	3.0 – 6.0

The volumetric test results showed that the rCB and control asphalt mixes were comparable.

Both the rCB and control asphalt mixes were within the air voids range for a Medium duty dense graded asphalt as required by TMR MRTS30.

Table 2.2: Laboratory asphalt performance properties – Resilient modulus

Testing Summary	Control Asphalt	rCB Asphalt	TMR MRTS30
Average air voids (%)	5.2	4.7	5.0 ± 1.0
Resilient modulus (MPa)	4,991	5,355	To be reported

The rCB asphalt mix provided a slightly higher resilient modulus values than the control asphalt mix.

Table 2.3: Laboratory asphalt performance properties – Stripping potential (Moisture sensitivity)

Testing Summary		Control Asphalt	rCB Asphalt	TMR MRTS30
Moisture Sensitivity	Average tensile strength - dry subset (kPa)	857	942	-
	Average tensile strength - moisture conditioned (freeze thaw) subset (kPa)	781	803	≥ 600
	Tensile Strength Ratio (%)	91	85	≥ 80

Both the rCB and control asphalt mixes were within requirements of for average tensile strength - moisture conditioned (freeze thaw) subset and tensile strength ratio.

Although the tensile strength ratio of the rCB asphalt mix was lower than the control asphalt both the moisture conditioned (freeze thaw) and dry subset tensile strengths increased.

Table 2.4: Laboratory asphalt performance properties – Deformation resistance

Testing Summary	Control Asphalt	rCB Asphalt	TMR MRTS30
Average final deformation rut depth (mm)	1.6	2.0	≤ 4.0

Both the rCB and control asphalt mixes were within the final rut depth requirements of ≤ 4.0 mm of TMR MRTS30.

The rCB asphalt mix provided a slightly lower final deformation rut depth than the control asphalt mix.

Table 2.5: Laboratory asphalt performance properties – Stability of asphalt (Hamburg)

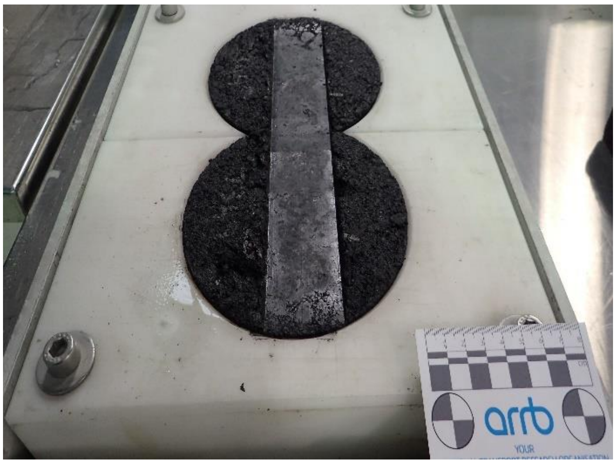
Testing Summary	Control Asphalt	rCB Asphalt
Average rut depth at termination cycles (mm)	4.9	4.4

Stability of asphalt is not currently required as a performance measure in TMR MTRS30, however this test determines the stability of asphalt mixes under loading while submerged in water. This test is primarily used to determine the susceptibility of an asphalt mix to failure by means of moisture damage, poor binder properties or structural weakness of the sample in the presence of high temperatures and/or water.

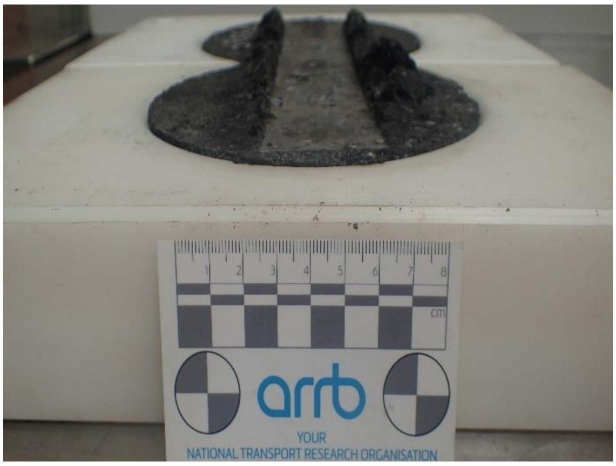
The rCB asphalt showed a lower average rut depth at termination cycles compared to the control asphalt. Note that no stripping inflection point was observed for either the rCB or control asphalt mixes.

After completion of testing the rCB asphalt specimens had minimal indication of stripping and were distinctly black in appearance (refer to Figure 2.1)

Figure 2.1 Stability of asphalt (Hamburg) visual comparison



rCB asphalt Hamburg tracking view



Control asphalt Hamburg tracking view

rCB asphalt Hamburg top view

Control asphalt Hamburg top view

Table 2.6: Laboratory asphalt performance properties – Flexural stiffness

Testing Summary		Control	rCB Asphalt
Stiffness at 10 Hz	E* calculated at 5 °C (MPa)	12,660	12,305
	E* calculated at 10 °C (MPa)	11,195	10,999
	E* calculated at 20 °C (MPa)	7,514	7,619
	E* calculated at 30 °C (MPa)	4,070	4,282

Flexural stiffness of asphalt is not currently required as a performance measure in TMR MTRS30. However, the flexural stiffness is used as an input parameter for the thickness design of asphalt pavements to determine the operating strain at the bottom of the asphalt layer.

Undertaking flexural stiffness testing on asphalt beam specimens at multiple temperatures (e.g. 5 °C, 10°C, 20 °C and 30 °C) and frequencies (0.1 Hz, 0.5 Hz, 1.0 Hz, 3.0 Hz, 5.0 Hz, 10.0 Hz, 20 Hz and 30 Hz) are used to create master curves for asphalt mixes.

Master curves are used to develop relationships for combinations of loading speeds and temperatures within any range covered by the conditions selected. Refer to Appendix A.1 and A.2 for the flexural stiffness experimental data for the control and rCB asphalt mixes.

In the example shown above the temperature and frequency characteristics are used to determine the stiffness of the rCB and control asphalt mixes at 10 Hz.

At the temperatures shown and at the chosen frequency both the rCB and control asphalt mixes are comparable.

Table 2.7: Laboratory asphalt performance properties – Fatigue life

Testing Summary	Control	rCB Asphalt
Estimated fatigue life at 20 °C (με)	140	144

Fatigue life of asphalt is not currently required as a performance measure in TMR MTRS30. However, the fatigue life of an asphalt is used to determine the resistance of as asphalt to failure under repeated traffic loading.

The rCB asphalt mix had a marginally higher fatigue life than the control asphalt.

2.2 Test results comparison of aged and unaged Logan City Council plant mix

The Logan City Council project investigated the impact of aging on the various asphalt mixtures. The aging process was used to simulate the insitu aging that occurs over the service life of the asphalt which in this case is equivalent to 7 to 10 years. The comparison of the properties on asphalt specimens manufactured from plant mix provided by Austek for this trial are shown below.

Table 2.8: Plant mix volumetric test results

Testing Summary		Control Asphalt	rCB Asphalt	TMR MRTS30 Production tolerance
Volumetrics	Average maximum density (t/m^3)	2.511	2.518	2.460 - 2.530
	Average bulk density (t/m^3)	2.386	2.372	-
	Average air voids (%)	5.0	5.8	-

The volumetric test results showed that the rCB and control asphalt mixes were comparable with the air voids of the rCB asphalt being higher than the control.

Both the rCB and control asphalt mixes were within the nominated maximum density during production tolerance as required by TMR MRTS30.

Table 2.9: Plant mix asphalt performance properties – Resilient modulus

Testing Summary	Lab prepared from reheated plant mix (Logan City Council)			
	Control asphalt		rCB asphalt	
	Unaged	Aged	Unaged	Aged
Resilient modulus (MPa)	6,400	7,200	8,400	9,000
% change due to aging	13		7	

The rCB asphalt mix provided a higher resilient modulus value than the control asphalt mix. The rCB asphalt mix showed a smaller percentage change due to aging.

Table 2.10: **Plant mix asphalt performance properties – Flexural stiffness**

Testing Summary		Lab prepared from reheated plant mix (Logan City Council)			
		Control asphalt		rCB asphalt	
		Unaged	Aged	Unaged	Aged
Stiffness at 10 Hz	E* calculated at 5 °C (MPa)	14,954	14,666	12,553	14,615
	% change due to aging	-2		16	
	E* calculated at 10 °C (MPa)	13,550	13,405	11,568	13,326
	% change due to aging	-1		15	
	E* calculated at 20 °C (MPa)	9,680	10,050	8,808	10,087
	% change due to aging	4		15	
	E* calculated at 30 °C (MPa)	5,463	6,545	5,790	6,761
	% change due to aging	20		17	

In the example shown above the temperature and frequency characteristics are used to determine the stiffness of the rCB and control asphalt mixes at the four temperatures shown above and 10 Hz.

The rCB asphalt mix had a consistent percent charge due to aging and had stiffness values that were comparable with the aged control asphalt.

The control asphalt mix had a lower percent change due to aging at three temperatures and a significant increase in the percentage change due to aging

There is a significant increase in the stiffness due to aging for the rCB mixture (i.e. the stiffness performance will increase over time) and effectively no change to the stiffness of the control asphalt due to aging except at higher temperatures.

Table 2.11: Test mix performance test summary control asphalt compared to rCB asphalt design

Testing Summary	Lab prepared from reheated plant mix (Logan City Council)			
	Control asphalt		rCB asphalt	
	Unaged	Aged	Unaged	Aged
Estimated fatigue at 20 °C (με)	151	137	143	171
% change due to aging	-9		20	

The rCB asphalt mix had a significantly higher fatigue life due to aging where the control asphalt had a lower fatigue life due to aging.

The resistance to fatigue of the rCB will improve over time whereas the control mix will decrease over time.

References

Australian and New Zealand Standards

AS/NZS 2891.5:2015, Methods of sampling and testing asphalt - Compaction of asphalt by Marshall method and determination of stability and flow - Marshall procedure

AS/NZS 2891.7.1:2015, Methods of sampling and testing asphalt – Method 7.1: Determination of maximum density of asphalt – Water displacement method

AS/NZS 2891.8:2014, Methods of sampling and testing asphalt – Voids and volumetric properties of compacted asphalt mixes

AS/NZS 2891.9.2:2014, Methods of sampling and testing asphalt – Method 9.2: Determination of bulk density of compacted asphalt – Presaturation method

AS/NZS 2891.13.1:2013, Methods of sampling and testing asphalt - Determination of the resilient modulus of asphalt - Indirect tensile method

Austroads

AGPT/T231:2006, Deformation resistance of asphalt mixtures by the wheel tracking test

AGPT/T232:2007, Stripping potential of asphalt – Tensile strength ratio

AGPT/T274: 2016, Characterisation of Flexural Stiffness and Fatigue Performance of Bituminous Mixes

Department of Transport and Main Roads Queensland

Technical Specification, MRTS30 Asphalt Pavements:2022

Test Method Q325:2021: Stability of asphalt – Hamburg wheel tracking device (HWTD)

Appendix A Master curve experimental data

A.1 Control asphalt mix

Temperature (°C)	Frequency (Hz)	Complex modulus for replicate specimens (MPa)				Statistics		
		7314-1	7314-2	7314-3	7314-4	Mean (MPa)	STDEV (MPa)	CoV (%)
5	0.1	8,110	8,355	7,867	8,322	8,163	226	2.8%
	0.5	9,480	9,965	9,798	10,004	9,812	239	2.4%
	1	10,295	10,789	10,267	10,879	10,558	321	3.0%
	3	11,576	11,791	11,611	11,888	11,716	148	1.3%
	5	11,928	12,191	12,092	12,348	12,140	176	1.5%
	10	12,456	12,684	12,595	12,800	12,634	145	1.1%
	20	12,595	12,866	12,739	12,935	12,783	150	1.2%
	30	13,433	14,068	13,548	14,211	13,815	382	2.8%
10	0.1	6,782	6,394	6,465	6,247	6,472	226	3.5%
	0.5	8,643	8,467	7,935	7,872	8,229	384	4.7%
	1	9,223	8,958	8,709	9,015	8,976	211	2.4%
	3	10,564	10,496	9,976	9,673	10,177	427	4.2%
	5	11,029	10,929	10,590	10,647	10,799	213	2.0%
	10	11,478	11,295	10,940	11,162	11,219	226	2.0%
	20	11,705	11,360	10,984	11,412	11,365	296	2.6%
	30	12,386	12,480	11,928	12,396	12,298	250	2.0%
20	0.1	2,909	2,747	2,618	2,565	2,710	153	5.7%
	0.5	4,348	3,924	3,667	4,070	4,002	284	7.1%
	1	4,956	5,043	4,704	4,632	4,834	197	4.1%
	3	6,256	6,515	5,572	6,120	6,116	398	6.5%
	5	6,734	6,518	6,084	6,124	6,365	315	4.9%
	10	7,749	7,684	7,297	7,230	7,490	264	3.5%
	20	8,351	8,384	7,930	7,968	8,158	243	3.0%
	30	9,354	9,624	9,341	9,013	9,333	250	2.7%
30	0.1	1,275	1,223	1,109	1,010	1,154	118	10.3%
	0.5	1,823	1,799	1,722	1,666	1,753	72	4.1%
	1	2,300	2,297	1,992	2,053	2,161	161	7.5%
	3	3,873	3,010	2,803	3,199	3,221	464	14.4%
	5	3,813	3,422	3,337	3,016	3,397	328	9.6%
	10	4,335	4,188	3,957	3,970	4,113	182	4.4%
	20	4,961	4,664	4,531	4,155	4,578	334	7.3%
	30	5,328	5,427	5,341	5,115	5,303	133	2.5%

A.2 rCB asphalt mix

Temperature (°C)	Frequency (Hz)	Complex modulus for replicate specimens (MPa)				Statistics		
		7314-1	7314-2	7314-3	7314-4	Mean (MPa)	STDEV (MPa)	CoV (%)
5	0.1	8,882	8,195	8,427	8,408	8,478	289	3.4%
	0.5	11,102	9,475	10,223	10,063	10,216	673	6.6%
	1	11,203	10,405	10,647	10,564	10,705	347	3.2%
	3	11,900	10,983	11,617	11,725	11,556	399	3.5%
	5	12,610	11,323	11,970	12,032	11,984	526	4.4%
	10	13,094	11,655	12,380	12,507	12,409	591	4.8%
	20	13,488	11,791	12,659	12,791	12,682	697	5.5%
	30	14,176	12,681	12,806	13,270	13,233	678	5.1%
10	0.1	7,499	6,575	6,946	6,991	7,003	380	5.4%
	0.5	8,881	8,147	8,040	8,764	8,458	426	5.0%
	1	10,072	8,646	9,075	8,885	9,170	626	6.8%
	3	10,536	9,567	9,897	10,251	10,063	421	4.2%
	5	10,923	9,952	10,308	10,645	10,457	420	4.0%
	10	11,371	10,280	10,640	11,010	10,825	470	4.3%
	20	11,310	10,326	10,732	11,237	10,901	462	4.2%
	30	12,846	11,451	11,793	11,897	11,997	597	5.0%
20	0.1	3,306	2,977	3,003	3,139	3,106	151	4.9%
	0.5	4,898	3,945	4,435	4,534	4,453	393	8.8%
	1	5,672	5,158	5,126	5,254	5,302	252	4.8%
	3	6,642	6,529	6,165	5,961	6,324	316	5.0%
	5	7,010	6,458	6,509	6,577	6,639	252	3.8%
	10	7,918	7,456	7,464	7,570	7,602	217	2.9%
	20	8,398	7,986	7,907	8,184	8,119	219	2.7%
	30	9,234	8,843	8,868	9,033	8,994	180	2.0%
30	0.1	1,472	1,264	1,214	1,290	1,310	113	8.6%
	0.5	2,342	2,007	1,904	1,942	2,049	200	9.8%
	1	2,557	2,457	2,283	2,391	2,422	115	4.7%
	3	3,456	3,745	3,163	3,385	3,437	240	7.0%
	5	3,902	3,593	3,330	3,512	3,584	238	6.6%
	10	4,632	4,328	4,101	4,368	4,357	218	5.0%
	20	5,161	4,688	4,768	4,885	4,875	207	4.2%
	30	6,210	5,882	5,776	6,010	5,970	187	3.1%

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